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16. ABSTRACT

The report is one in a six-volume series considering abnormal operating conditions (AOCs) in the primary section (sintering, blast furnace ironmaking, open hearth, electric furnace, and basic oxygen steelmaking) of an integrated iron and steel plant. Pollution standards, generally based on controlling discharges during normal (steady-state) operation of a process and control system, are often exceeded during upsets in operation. Such periods of abnormal operation are becoming recognized as contributing to excess air emissions and water discharges. In general, an AOC includes process and control equipment startup and shutdown, substantial variations in operating practice and process variables, and outages for maintenance. The purpose of this volume, which covers the basic oxygen process, is to alert those who deal with environmental problems on a day-to-day basis to the potential problems caused by AOCs, to assist in determining the extent of the problems is a specific plant, and to help evaluate efforts to reduce or eliminate the problems. The report enumerates as many AOCs as possible, with emphasis on those which have the most severe environmental impact. Descriptions include flow diagrams, material balances, operating procedures, and conditions representing typical process configurations.

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Pollution	Starting	Pollution Control	13B
Iron and Steel Industry	Shutdowns	Stationary Sources	11F
Basic Converters		Basic Oxygen Process	
Oxygen Blown Converters		Abnormal Operations	
Abnormalities			
Failure			

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by

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19

PREFACE

This study of the environmental effects of substandard, breakdown, or abnormal operation of steelmaking processes and their controls has been made to provide needed perspective concerning these factors and their relevance to attainment of pollution control. The use of the term Abnormal Operating Condition (AOC) herein, in characterizing any specific condition should not be construed to mean that any operator is not responsible under the Clean Air Act as amended for designing the systems to account for potential occurrence in order to comply with applicable State Implementation Plans or New Source Performance Standards.

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The project was carried out in RTI's Energy and Environmental Research Division under the general direction of Dr. J. J. Wortman. The work was accomplished by members of the Process Engineering Department's Industrial Process Studies Section, Dr. Forest O. Mixon, Jr., Department Manager, Mr. Ben H. Carpenter, Section Head.

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TABLE OF CONTENTS

Page

LIST OF FIGURES vii

LIST OF TABLES viii

INTERNATIONAL SYSTEM OF UNITS AND ALTERNATIVE (METRIC) UNITS WITH CONVERSION FACTORS ix

1.0 INTRODUCTION 1

- 1.1 Purpose and Scope 1
- 1.2 Definition of AOC 2

2.0 Steelmaking in the Basic Oxygen Process Furnace 3

- 2.1 Flow Sheet 5
- 2.2 Material Balance 10
- 2.3 Methods of Operation 12
  - Top Blown Furnace 12
  - Bottom Blown Furnace 14
- 2.4 Pollution Sources 14
  - Air Pollution 14
  - Water Pollution 18

3.0 CONTROL TECHNIQUES AND EQUIPMENT 19

- 3.1 Emission Standards 19
- 3.2 Primary Emissions Control 20
  - Equipment Configurations 21
    - Precipitator System Hardware 21
    - Precipitator Startup 26
    - Precipitator Maintenance 27
    - Scrubber System Hardware--Combustion Hood 28
    - Scrubber Startup 32
    - Scrubber Shut Down 33
    - Scrubber Maintenance 33
    - Scrubber System Hardware--Closed Hood 34
- 3.3 Secondary Emissions Control 38
  - Secondary System -- Maintenance 40

4.0 ABNORMAL OPERATING CONDITIONS 41

- 4.1 Process Related 41

TABLE OF CONTENTS (cont'd)

Page

4.1.1 Startup 41

Burn In 41

4.1.2 Shut Down 43
4.1.3 Abnormal Operating Conditions 43

Puffing at Hood 42
Improper Transfer of Hot Metal to Vessel 43
Improper Charge Material 44
Foaming and Slopping 45
Relief Damper Opening 47
Pit or Charging Explosions 50
Running Stopper 50

4.2 Control Equipment Related 51

4.2.1 Startup 52

Precipitator Warmup 52
Stack Puff 54
Unbalanced Flow Among Manifolded Fans 55
Insufficient Draft 56

4.2.2 Shut Down 57

Dampers Stuck or Jammed 57

4.2.3 Abnormal Operating Conditions 58

Downtime of Primary Collection Systems 58
Downtime of Secondary Systems 61
Precipitator Commong 63

1) Wire Breakage 63
2) Sprays Plugged or Corroded 66
3) Insufficient Conditioning of Gases 67
4) Corroded Pump Impeller, Pump Failure 67
5) Transformer-Rectifier Set Failure 68
6) Insulator Failures 68
7) Rapper Failure 69
8) Dust Removal System Breakdown 70

Scrubbers Common 71

1) Sprays Corroded or Plugged 71
2) Plugged or Corroded Pipes 73
3) Corroded Pump Impellers, Pump Failure 74
4) Plugged or Failed Demister 74
5) Drum Filter Failure 75
6) Acid Cleaning Scrubber Components 76
7) Unbalanced Water System 76

TABLE OF CONTENTS (cont'd)

Page

Baghouse Common 77

1) Bag Breakage or Plugging 77
2) Shaker or Reverse Air System Failure 78
3) Open Bypass Damper 79
4) Dust Removal System Breakdown 80

Fan Common 81

1) Draft Loss 81
2) Fan Failure 82

Other 83

1) Loss of Instrument Air 83
2) Failure to Flare Gas 83

5.0 TABULATED SUMMARY OF AOC 84

6.0 REFERENCES 92

LIST OF FIGURES

Figure		Page
1	BOP -- schematic elevation of a two furnace facility	6
2	BOP -- schematic cross-section of operating units	7
3	BOP furnace flow sheet	8
4	Typical configuration for a precipitator installed on a BOP furnace	22
5	Typical configuration for a scrubber installed on a BOP furnace with an open or combustion hood	29
6	Typical configuration for a scrubber installed on a BOP with a closed hood	35

LIST OF TABLES

Table		Page
1	Emissions and Effluent Limitations	19
2	Basic Oxygen Process Abnormal Operating Conditions	85

INTERNATIONAL SYSTEM OF UNITS AND ALTERNATIVE (METRIC) UNITS WITH CONVERSION FACTORS

Quantity	SI Unit/Modified SI Unit	Equivalent To
mass	kg	2.205 lb
	Mg (megagram = 10^6 grams)	2205 lb
	Mg	1.1025 ton
	Gg (gigagram = 10^9 grams)	
volume	m^3 (cubic meter)	35.32 cf
	dscm (dry standard cubic meter)	
	scm (standard cubic meter: 21°C, 1 atm)	
	ℓ (liter = 0.001 m^3)	
concentration or rate	g/m^3 (grams/m^3)	0.437 gr/ft^3
	mg/m^3 (milligrams/m^3)	0.000437 gr/ft^3
	g/kg	2 lb/ton
energy	J (joule)	0.000948 Btu
	kJ/m^3 (kilojoules/m^3)	0.02684 Btu/ft^3
	MJ (megajoules = 10^6 joules)	
	MJ/Mg	0.430 Btu/lb 859 Btu/ton
force	kPa (kiloPascal)	0.146 lb/in^2
	1 Pascal = 1 N/m^2 (Newton/m^2)	
area	m^2 (square meter)	10.76 ft^2

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

Air and water pollution standards, generally based upon control of discharges during normal (steady-state) operation of a control system, are frequently exceeded during "upsets" in operation. When such upsets become repetitive and frequent, the regional and local enforcement agencies undertake, through consent agreements, to work with the plant toward resolution of the problem, and plans are developed for such equipment and operating practice changes as will eliminate or alleviate the frequent violations. Should the planning process fail to resolve abnormally frequent occurrences of abnormal operating conditions, the problem may lead to litigation. Thus, periods of abnormal operation are becoming recognized as contributing to the emission of high concentrations of pollutants. Similarly, upsets contribute to spills of excessive amounts of effluent-borne pollutants into waterways.

There is a need for information concerning abnormal operating conditions (AOC): their identity, cause, resulting discharges, prevention, and minimization.

The purpose of this manual is to alert those who deal with environmental problems on a day-to-day basis to the potential problem areas caused by abnormal conditions, to assist in determining the extent of the problem created by abnormal conditions in a specific plant, and to provide help in evaluating any efforts to reduce or eliminate the problems. The processes considered are those in the primary section of the integrated iron and steel plant. Included are the sintering, blast furnace ironmaking, open hearth, electric furnace, and basic oxygen steelmaking. This manual covers the basic oxygen process.

This manual is based on reviews of somewhat limited data, visits to a few of the many steel plants, interviews with persons intimately involved in either steelmaking or attendant environmental regulations, and the expertise of the study team. It is, therefore, a preliminary assessment which concentrates on enumerating as many of the conditions as possible, with emphasis on those which have the most severe environmental impact.

Each process is described separately. Descriptions include flow diagrams and material balances, operating procedures and conditions. The flow sheets and material balances presented are representative of the most typical process configurations.

Within each process are variations, both in the process itself and in the equipment for control of pollution. Variations in equipment and process are accompanied by variations in AOC. It is, therefore, of value to identify as many of the variations as possible. At the same time, it is necessary to limit consideration of the numerous alternatives to those which are currently in greatest application and use.

1.2 DEFINITION OF AOC

In general, an abnormal operating condition (AOC) is considered to be that which departs from normal, characteristic or steady-state operation, and results in increased emissions or discharges. In addition to abnormal operations, this study includes startup and shut down difficulties of processes and control equipment. It also includes substantial variations in operating practice and process variables, and outages for maintenance, either scheduled or unscheduled.

The use of the term Abnormal Operating Condition (AOC) in characterizing any specific condition should not be construed to mean that any operator is not responsible under the Clean Air Act as amended for designing the systems to account for potential occurrence in order to comply with applicable State Implementation Plans or New Source Performance Standards.

2.0 STEELMAKING IN THE BASIC OXYGEN PROCESS FURNACE

The basic oxygen process (BOP) furnace receives a charge composed of molten iron and scrap and converts it to molten steel. A jet of high purity oxygen oxidizes the carbon and the silicon in the molten iron in order to remove these products and to provide heat for melting the scrap. After the oxygen jet is started, lime, usually in the form of pebble lime, is added to the top of the bath to provide a slag of the desired basicity. Fluorspar and mill scale are also added in order to achieve the desired slag fluidity.

The basic oxygen steelmaking process is essentially a thermochemical process which lends itself, more or less, to the application of computer control. The process starts with the analysis of the composition of the molten iron and its temperature. These data are applied to the desired chemistry of the finished product and computations are made which determine the percentage of molten iron, the percentage of scrap, the amount of flux materials and the amount of alloy additions. If all goes exactly as planned, after the injection of the precalculated amount of oxygen, the vessel is turned down, a steel analysis is made, and the heat is tapped. If, on the other hand, the heat is off analysis, it may be necessary to either blow with additional oxygen to elevate temperature and/or cool the steel by coolant additions to the bath.

A basic oxygen furnace facility is generally arranged with three parallel aisles. One aisle, called the charging aisle, has one or more cranes for handling charge materials, that is, molten iron and scrap, to the furnace, as well as handling ladles of molten slag away from the furnace. The second aisle, called the furnace aisle, contains the furnaces, the collection hoods for the fumes, the lances for injecting the oxygen into the bath, and also the overhead bins for storing and metering out the various flux materials and alloy additions. The third aisle, the pouring aisle, serves to handle the finished heats of steel. It has one or more overhead cranes and facilities for receiving the heat of steel either into ingot molds or into continuous casting machines.

Adjacent to and generally parallel to the charging aisle, there is a scrap yard with overhead cranes where scrap is transferred from railroad cars into the charging boxes. The charging boxes are moved by special railed cars from the scrap yard into the charging aisle. There are also railed cars which are under the furnace. These cars hold the steel and slag ladles and serve to transfer the ladles from under the furnace to the charging aisle in the case of the slag or to the pouring aisle in the case of the steel.

During the oxygen blow, the oxygen lance is lowered through a special hole in the top wall of the hood, is stopped a short distance above the bath of steel and the oxygen flow is initiated. The vessel is upright during the blow and the fumes have a direct access from the mouth of the furnace into the mouth of the hood. At other times in the process, the vessel may be tilted so that the mouth of the vessel does not align with the opening in the hood and capture of the fumes becomes more difficult. The vessel is tilted toward the charging aisle for at least four of the operations; namely, charging with scrap, charging with molten iron, sampling the heat for analysis and dumping the slag. It is tilted toward the pouring aisle usually only when pouring the finished heat of steel from the furnace into the steel ladle. Alloy additions may be made to the bath while it is upright under the hood. However, the normal case is to make them to the ladle while it is being filled with steel from the furnace.

There are several ancillary operations associated with the basic oxygen process for making steel. The first is the scrap handling operation which was described above. The next is the transfer of molten iron from the railroad ladle to the shop ladle and from the shop ladle to the furnace itself. The handling of molten iron may include the operation of mechanically skimming slag from the top of the bath of iron. A third operation is the teeming of the finished steel into ingot molds or into continuous casting machines. Finally, there is the handling and disposing of molten slag, generally accomplished by carrying the ladle of slag to the end of the shop and pouring it on the ground or into slag pots where it is allowed to cool. The solidified slag is then loaded into trucks or railroad cars for transport to a disposal site. Alternately, the molten slag may be carried by means of special trucks directly to the disposal site.

A BOP shop generally has either two or three steelmaking vessels. In either case, one of the vessels is generally out of service for a reline, while the other one or two are in operation. In the two-vessel shop, oxygen is blown intermittently, generally for a period of about 20 minutes of the total heat time. In a three-vessel shop, the operation of the two on-line vessels are staggered so that blowing alternates from one vessel to the other and so that two vessels are not blown at the same time.

Figure 1 shows a schematic elevation of a typical two furnace shop and indicates all of the facilities which have been described above. Figure 2 shows a schematic cross-section which indicates the various operating units.

2.1 FLOW SHEET

The flow sheet for steelmaking in the BOP furnace is shown in Figure 3.

The principal components of the charge are molten iron and scrap. Scrap is received in the shop by means of railroad gondola cars and is transferred to the charging box by means of an overhead magnet and crane. Molten iron is brought to the shop by means of railroad ladle cars and is transferred to the shop ladle at the ladle transfer station. This station is often equipped with a hood for capturing the kish (exuded carbon) which evolves during the transfer operation. When the vessel is ready for charging, it is tilted toward the charging aisle and the charging box lifted and dumped into the vessel. Next, the ladle of molten iron is poured into the vessel over the scrap. The vessel is turned upright, the oxygen lance lowered, and the blow commences. Immediately after the start of the blow, lime and fluorspar in the desired quantities are fed through the chute into the vessel from the weigh hopper.

The gases which evolve from the steelmaking operation are captured by the hood, enter the hood cooling section, where some heat is extracted and pass through the conditioning chamber where the gas is cooled to the required temperature for the precipitator and at the same time humidified for proper precipitator operation. The gas cleaning system consists of precipitators, fans, dust handling equipment, and a stack for carrying away the cleaned gases.

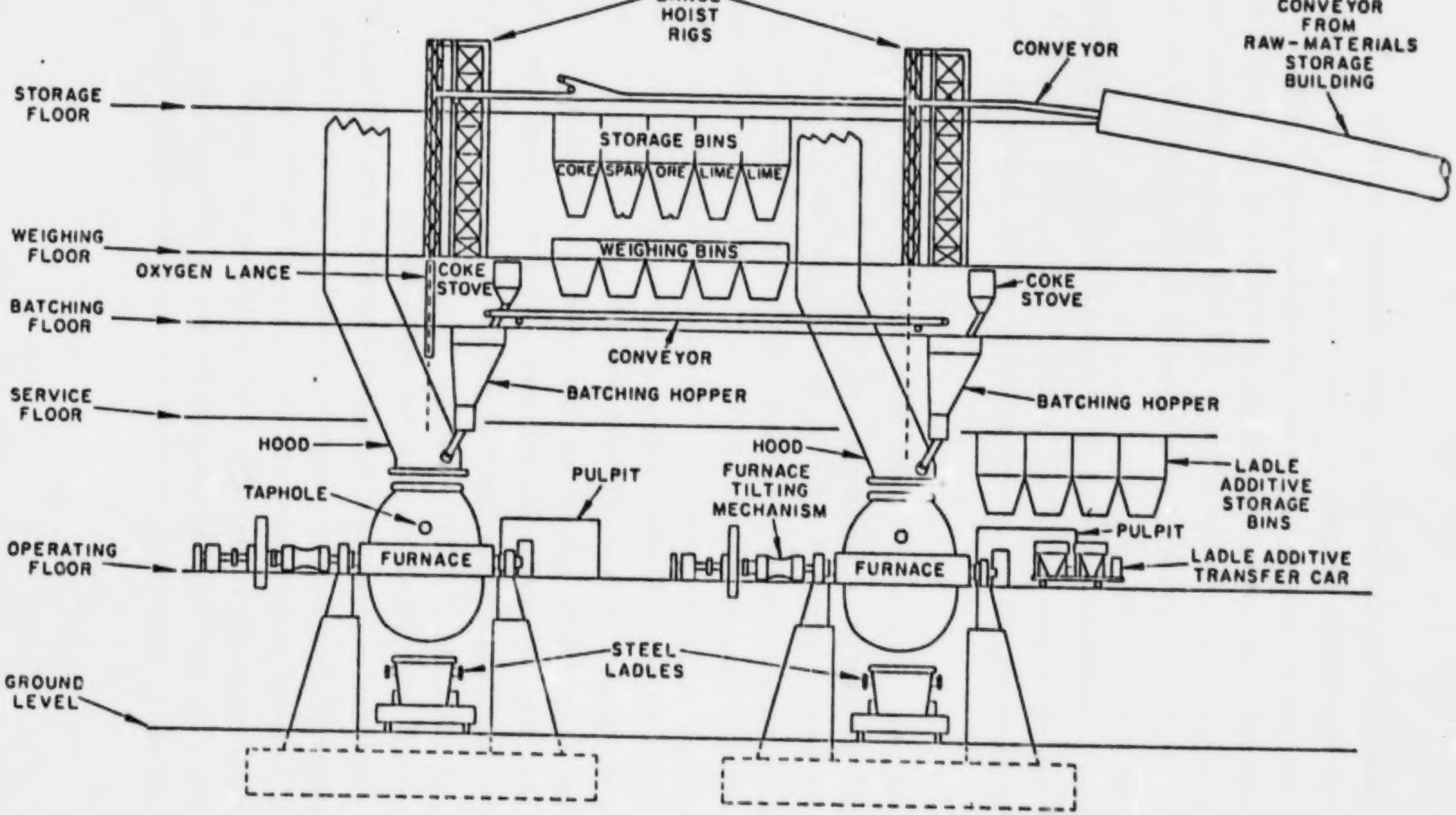

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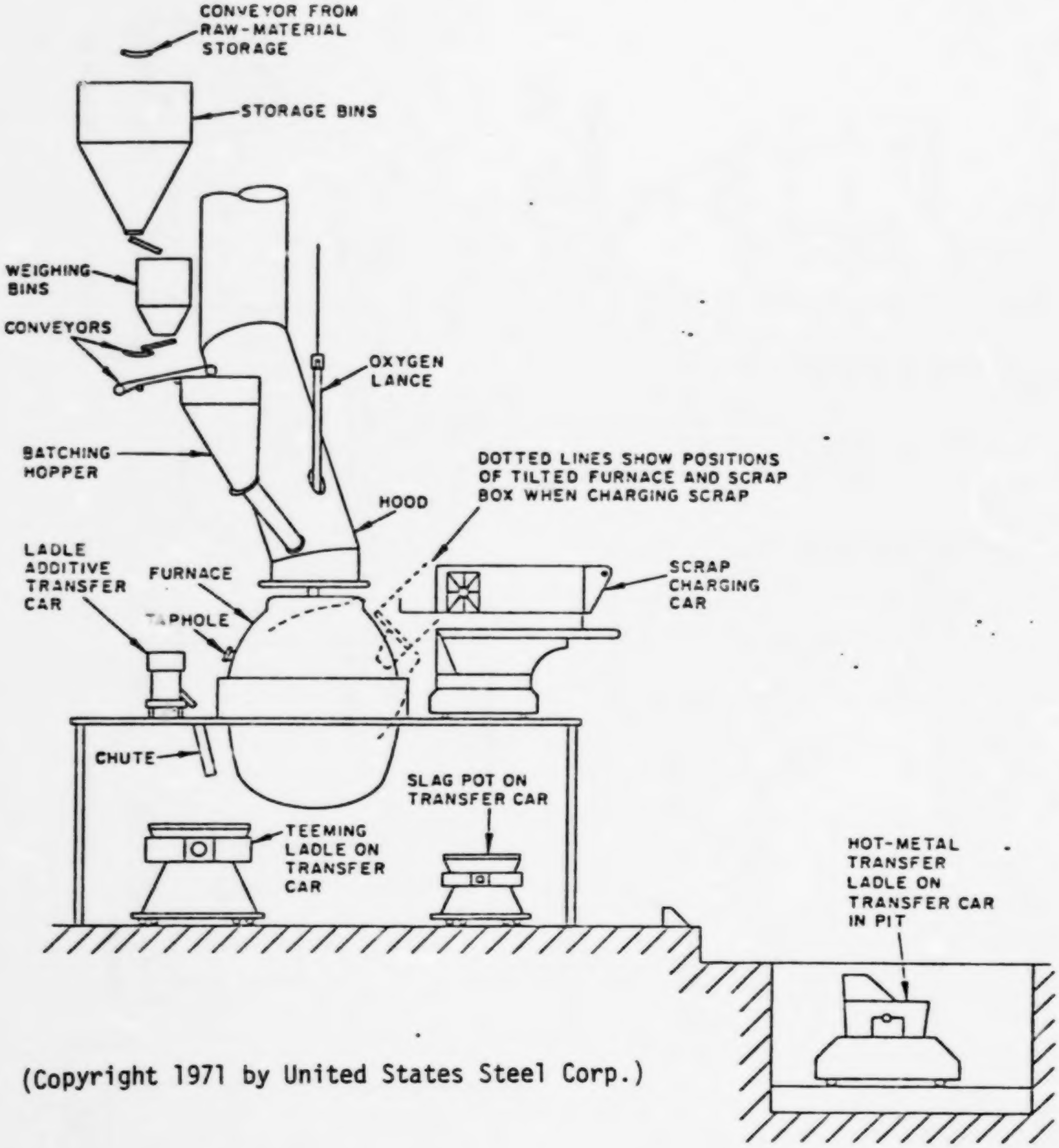
Figure 1. BOP -- schematic elevation of a two furnace facility.


CONVEYOR FROM RAW-MATERIAL STORAGE
STORAGE BINS
WEIGHING BINS
CONVEYORS
OXYGEN LANCE
BATCHING HOPPER
HOOD
DOTTED LINES SHOW POSITIONS OF TILTED FURNACE AND SCRAP BOX WHEN CHARGING SCRAP
LADLE ADDITIVE TRANSFER CAR
FURNACE
TAPHOLE
SCRAP CHARGING CAR
CHUTE
SLAG POT ON TRANSFER CAR
TEEMING LADLE ON TRANSFER CAR
HOT-METAL TRANSFER LADLE ON TRANSFER CAR IN PIT

(Copyright 1971 by United States Steel Corp.)

Figure 2. BOP -- schematic cross-section of operating units.

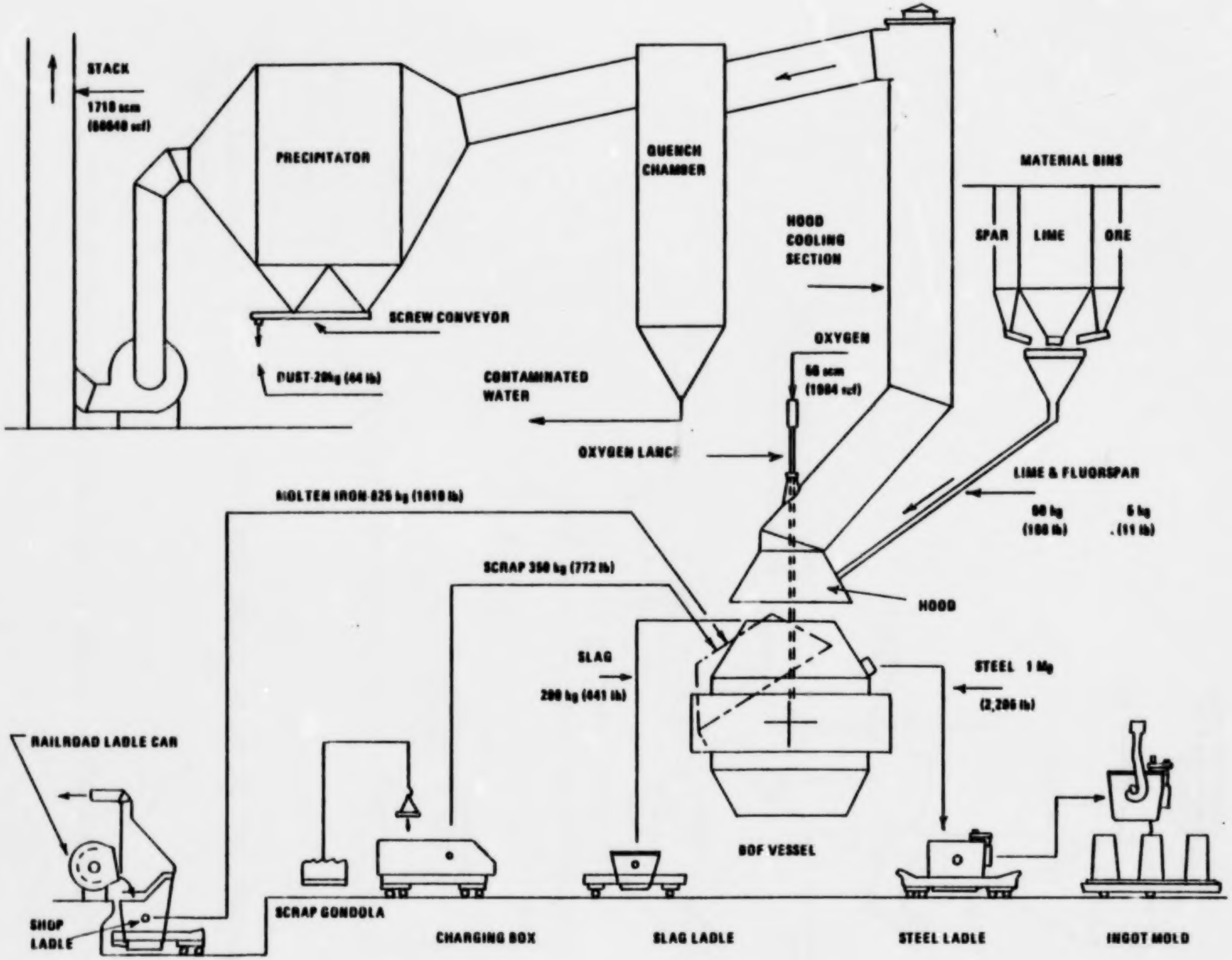


Figure 3. BOP flow sheet.

Two other forms of gas cleaning equipment are in common use. One is the open hood which is similar to that shown in Figure 3, but connected to a scrubber system. The other is the closed hood in which the diameter of the entry into the hood is roughly the same as the diameter of the mouth of the vessel and in which the lower portion of the hood is equipped with a skirt that can be dropped onto the mouth of the vessel, sealing off the space between the hood and the vessel proper. In this manner, the gases are collected in an uncombusted state; their volume is reduced as compared to those in the open hood and the yield of the process is increased. Because the gases are combustible, gas cleaning is performed by means of a scrubber, the precipitator being a potential source of explosions. The gas from the closed system may be stored in a holder and utilized as an energy source. If not, it must be flared at the top of the stack.

Because there is no danger of explosion in the open hood system, all of the vessels in the shop may be connected to a common gas cleaning system, thereby effecting economies in installation and increasing reliability due to standby units. The closed system, on the other hand, because of the danger of explosion, must have a separate scrubber system for each vessel.

The flux bins are generally filled by a belt conveyor system from a hopper at ground level. This hopper is usually equipped to be loaded from a railroad car, or a truck, or both. Transfer points of the conveyor system are generally fitted with hooding and small individual baghouses.

When the heat is complete, the vessel is tilted and the steel is poured into the steel ladle. The transfer car moves the steel ladle into the pouring aisle, the crane picks up the ladle and carries it over to the train of ingot molds. A stopper or slide gate in the bottom of the ladle is opened and each ingot is filled in turn. Alternatively, the ladle may be carried to the top of a continuous casting machine for the production of continuously cast product. After the steel is out of the vessel, the slag is poured into a ladle or slag pots. When the ladle is filled, it is run into the charging aisle by means of a transfer car. The charging crane then picks up the ladle and carries it away for disposal.

Disposal of the slag may be accomplished by pouring it on the ground at the end of the shop. Alternatively, the ladle of molten slag may be carried away from the shop by a mobile vehicle and the slag processed in a remote site. In either case, the metallics are generally removed from the slag by magnetic means and returned to the blast furnace or sinter plant and charged as a portion of the burden. The remaining slag is generally disposed of in a dump area.

2.2 MATERIAL BALANCE

As indicated on the flow sheet, in order to produce a metric ton of steel in the BOP, the following raw materials are required:

1. Ferrous charge materials consisting of molten iron, approximately 70 percent, and scrap, approximately 30 percent (higher percentages of hot metal may be used if desired). The typical yield in a BOP with an open hood is 85 percent. Therefore, to produce 1000 kilograms (kg) (2205 pounds) of steel, 825 kg (1819 pounds) of molten iron and 350 kg (772 pounds) of scrap are required. In the closed hood, the yield increases to approximately 87 percent and the usage of molten iron and scrap drops correspondingly. Some of the shops practice scrap pre-heating prior to the admission of molten iron. This practice generally adds about 15 minutes to the tap-to-tap time; however, less molten iron and more scrap may be used. In general, the hot metal drops from 70 percent to 60 percent under scrap pre-heating.
2. Flux materials consisting of lime and fluorspar. Lime is the principal ingredient. Its quantity is generally about 90 kg per metric ton (198 pounds) of steel and varies corresponding to the sulfur content of the iron and the specification of the finished steel in regard to freedom from sulfur. The quantity of fluorspar is determined by the need to maintain a fluid slag and is generally 3 percent by weight of the amount of lime.
3. Oxygen in the amount of 3.1 standard cubic meters per minute (110 standard cubic feet per minute (scfm))/per metric ton of steel is injected into the bath. The amount of oxygen used depends on two factors. One is the composition of the molten iron, especially in respect to its content of such materials as silicon and manganese. The other is the final carbon level required in the finished steel.

4. Ladle additions consist of alloying elements such as manganese, nickel, chromium, etc., which are required in varying amounts depending upon the final composition of steel. In addition, aluminum may be added to cleanse the steel of dissolved oxygen. The aluminum reacts with oxygen forming aluminum oxide, most of which migrates to and is included with the slag.

The basic oxygen process, in addition to producing steel, yields slag, gases, and particulates in the gases. The amount of slag is essentially equal to the amount of lime and spar that is added to the bath plus additions for refining of the bath and less the emissions of slag to the hood along with the furnace gases.

The amount of gases from the furnace varies according to the type of fume collection system which is employed and is described below:

1. Open hood with ESP produces the greatest volume of gas, approximately 62 scmm per metric ton (2,000 scfm/ton) of steel. This high value results from two causes. One is the absolute necessity to completely combust all of the carbon monoxide which evolves from the furnace, thereby avoiding any possiblity of explosion in the precipitator. The other is that the precipitator in having a low pressure drop, generally under 51 mm (2 inches) of water gauge does not result in high consumption of energy at the fan, even though the volumes may be high. A supplementary benefit of the high volume is that it facilitates the capture of emissions from the mouth of the vessel when it is tilted partially out of the hood to receive scrap and molten iron.
2. Open Hood--Wet Scrubber generally produces less flow of gases than does the precipitator, the amount being approximately 28 scmm per metric ton (900 scfm/ton) of steel. The reasons for the reduced volume result from the need to conserve energy in a scrubber system operating somewhere in the range of 127 to 178 centimeters (cm) (50 to 70 inches) of water. Also, the presence of combustibles in the scrubber system would not entail a significant risk of explosion.
3. Closed Hood--Wet Scrubber involves the least flow of any of the three systems, approximately 16 scmm per metric ton (500 scfm/ton) of steel. This reduced value results because secondary air to complete the combustion of carbon monoxide is not permitted to enter the hood. Energy requirements for cleaning the gases in the closed system, because of the sharply reduced volumes, are lower than those for the open system.

The amount of particulates carried out of the furnace into the gas cleaning system amounts to about 6 to 20 kg per metric ton (12 to 40 pounds/ton) of steel produced.[1,2,3] Each of the gas cleaning systems described above are capable of reducing the concentration of particulates in the clean gas to the level of New Source Performance Standards, 50 milligrams (mg)/scm (0.022 grains per standard cubic foot (gr/scf))dry or better. The mass rate of particulates in the clean gas therefore depends essentially upon the volume of gas leaving the stack and in turn is related to the type of cleaning system employed. The environmental effectiveness of the three control systems ranked from lowest emission rate to highest is, in terms of particulate control, the closed hood, the open hood with a scrubber and the open hood with the precipitator.

2.3 METHODS OF OPERATION

Top Blown Furnace

In the basic oxygen steelmaking process, molten iron is converted to steel using a jet of oxygen to remove most of the carbon and silicon. The heat that is generated by oxidation is used to melt scrap. Refining of impurities is accomplished by means of the slag, the chief goal being to remove as much of the sulfur from the steel as is possible. The desired specifications of the end product are usually accomplished by the additions of suitable alloying materials to the ladle of finished steel as it is filled.

A typical BOP furnace produces a heat of steel in a very short time; tap-to-tap times in a high performance shop may be as little as 30 minutes. To accomplish this the process is fully mechanized and, in addition, is under some form of computer control. Computer control may be applied directly from the computer through electrical circuits to the furnace (DDC); however, the more usual practice is for the computer to provide information for the operator who then controls the process. High performance depends on equipment that is sophisticated and reliable. Both of these factors tend not only to produce steel at a rapid rate, but also to avoid abnormal operating conditions.

The lining of the BOP furnace is made of high quality basic refractory. During a campaign which may last 1000 heats or more, the linings become worn generally near the slag line. These points of wear are patched between heats by various gunning techniques (spraying of patching materials onto the wear points). Eventually linings wear so much that the furnace must be taken out of service, the refractory removed, and a new lining installed. About one week is required to remove the old lining and replace it with a new one. During this period, the vessel is out of service.

In a two-vessel shop, the vessels are alternated with each other in respect to on-time. One vessel is either being relined or, having been relined, is on standby and the other vessel is in operation. (Some two vessel shops operate both vessels when the reline is complete.) In a three-vessel shop, the relining schedule is arranged so that two vessels may be kept in operation. In this case, the two operating vessels are alternated one with the other in respect to the flow of oxygen. While one vessel is being blown, the other is being tapped and being recharged.

The nature of the process is such that when an upset occurs of potential damage to equipment, to the environment, or to the process itself, it is possible to shut it down instantly. All that is required is to stop the flow of oxygen and to raise the lance. The heat may remain in the vessel for a relatively long period of time, possibly six or more hours, until necessary repairs have been made. It is preferred, however, to dump the heat in the case of a long delay.

The hood which conveys the gases away from the furnace is water cooled. Water may be recirculated through a heat exchanger and returned again for use in the hood. Alternatively, the water may be converted to steam and delivered to other steelmaking operations. On some steam generating hoods, fuel is fired into the hood between blow periods in order to maintain a constant rate of steam output. Another way of maintaining the output at a constant rate is to use a steam accumulator; however, in this case, the generation of steam per ton of steel is less because there is no use of supplementary fuel.

As indicated above, it is possible to decrease the amount of molten iron required by using a technique of scrap pre-heating. This is accomplished by means of a second lance which is inserted in place of the oxygen lance. The second lance injects oxygen and natural gas or oil and pre-heats the scrap to a glowing red color. After pre-heating the scrap, the lance is withdrawn and the oxygen lance lowered in its place. The vessel is tilted and molten iron is poured into it. Pouring of molten iron over the heated scrap results in a violent reaction and the production of copious emissions. The pouring rate must be carefully controlled in order to insure that the hood may capture substantially all of the emissions.

Bottom Blown Furnace

An alternative to the use of an oxygen lance is found in the Q-BOP. This is a recent development in which oxygen and natural gas are injected through tuyeres in the bottom of the vessel. The metallurgy of the process, the ancillary equipment employed with the process, and the details of the fume collection system are generally the same as for the BOP.

The principal advantage claimed for the Q-BOP is that it requires less headroom in the furnace aisle than does the BOP. This has allowed the Q-BOP to be installed in an existing open hearth building, thereby saving cost in construction of the facility. The Q-BOP is also capable of producing steel at a somewhat faster rate than does the BOP.

When the Q-BOP vessel is tilted to receive scrap and molten iron, or to sample for steel analysis, it is necessary to maintain a flow through the tuyeres so that they may not become blocked. In normal practice, the oxygen and natural gas are turned off when the vessel is tilted and these gases are replaced by a flow of nitrogen. In any event, there is a copious flow of emissions of fumes from the mouth of the vessel due to the gas flow from the tuyeres. For this reason, the Q-BOP needs to be more fully enclosed at the level of the charging floor than is the BOP. In order to direct the gases back into the collection system and to protect the men who are on the charging floor, a pair of large horizontally sliding doors are provided. These doors are opened to permit the addition of scrap and molten iron; however, they are closed at all other times.

2.4 POLLUTION SOURCES

Air Pollution

The operations in the BOP shop are directly responsible for two general categories of pollution, namely, air pollution and solid waste. Water pollution, where it occurs, is invariably a byproduct of gas cleaning operations.

There are two principal types of air pollution. The first is the direct result of the steelmaking process itself and consists of dense emissions of fumes from the mouth of the basic oxygen vessel. The fumes are mostly metallic oxides which result from the reaction between the jet of oxygen and the molten bath. Also included in these fumes are particles of slag. Carbon monoxide produced by the reaction of both carbon and oxygen is also emitted. For some plants, raw materials used in the process contain fluoride that is emitted during the blow.

The gases which leave the mouth of the furnace, in addition to being dusty, are extremely hot. In the closed hood system, temperatures are in the neighborhood of 1650°C (3000°F). In the open system, CO combustion takes place at the entrance to the hood, raising the temperature perhaps another 540°C (1000°F). Before the gases may be cleaned of their particulate matter, it is necessary that they be cooled. The methods of cooling and of cleaning the gas are briefly described under Section 2.2. Control equipment is described in detail in Section 3.0.

The second type of air pollution source comprises a variety of operations from which the emissions are generally classed as fugitive emissions. Descriptions of these follow:

1. Reladling of molten iron from the torpedo railroad car to the shop ladle is accompanied by the emissions of kish, a mixture of fine iron oxide particulates together with larger graphite particles. The usual method of control is to provide a close fitting hood and a baghouse. A spark box between the hood and the baghouse protects the bags from destruction due to large hot particulates. Normally, the spark box is built integrally with the baghouse.

2. Desulfurizing of molten iron may be accomplished by means of various reagents such as soda ash, lime and magnesium, etc. Injection of the reagents is accomplished pneumatically, either with dry air or nitrogen. Desulfurizing may take place at various locations within the iron and steelmaking facility; however, if the location is the BOP shop, then it is most often accomplished at the reladling station to take advantage of the fume collection system at that location.

3. Skimming of slag from the ladle of molten iron serves the purpose of keeping this source of high sulfur out of the steelmaking process. Skimming results in the emissions of kish and for this reason is often done under a hood. The hood may be connected to a baghouse, or to just a vent stack.

4. Charging of scrap and molten iron into the BOP vessel results in a dense cloud of emissions. Emissions from the charging of scrap are particularly severe if the scrap is dirty, oily, otherwise contaminated, or contains such potential sources of explosion as excess water or ice. Emissions from the charging of molten iron are particularly severe if the scrap over which it has been charged is dirty or contaminated, or if the scrap has been preheated. In some facilities, if the main hood is large enough and the volume of air flow is also large enough, it is possible to capture most of the fumes in the main collection system for the vessel. In this case, as much of the vessel mouth as possible is kept under the hood and, in the case of pouring the iron, it is done at a slow, controlled rate. In other facilities, it is necessary to provide auxiliary hoods in front of the main collection hood. On occasion, a facility may also have a hood at the building monitor to capture any fumes which bypass the hoods at the vessel.

5. Pouring of the molten steel from the BOP vessel into the ladle results in iron oxide fumes. The quantity of fumes are substantially increased by additions into the ladle of such alloys as silicon, manganese, etc. Some BOP facilities enclose the space at the rear of the furnace in such a manner that the fumes are ducted into the main collection system. In other facilities the fumes are permitted to exit through the roof monitors.

6. Turning down the vessel for the purpose of taking samples or for pouring out the slag results in emissions. These emissions are particularly great in the case of the Q-BOP The reason for this is that, when turned down, a flow of nitrogen must be maintained in the tuyeres in the bottom of the latter vessel in order to keep out the molten metal and slag. Some facilities have a pair of sliding doors on the charging floor in front of the vessel. These doors are kept closed as much as possible in order to direct the fumes into the main collection system.

7. Slag handling may consist of transporting the ladle of molten slag from the shop to a remote dump area, or it may consist of dumping the molten slag on the ground at the end of the shop and cooling it there. In the latter case, the cooling of the slag as well as its subsequent digging by bulldozer is a very dusty operation that is generally uncontrolled.

8. Teeming of steel from the ladle to the ingot mold or concaster results in emissions which are normally uncontrolled. In some shops, where leaded steels are poured, the resultant fumes are extremely hazardous to the health of the workers. In this case, local hooding is provided.

9. Flux handling takes place in a sophisticated system comprising receiving hoppers from truck or railroad car, belt conveyors, large overhead storage bins, weigh hoppers, feeders, controls, etc. Hooding is provided at the various transfer points to capture the particulates which arise from the falling of the bulk material. Exhaust ducts lead from the hoods to one or more bag houses.

10. Skull burning and ladle dumping. Some molten metal remains in the ladle after teeming. Between successive uses the metal cools and solidifies. After accumulating for some time, these skulls may interfere with proper ladle operation, so they are burned out with oxygen lances. Iron oxide fume is emitted. Ladles must also be relined at intervals to protect the steel shell. The ladles are turned upside down to dump loose material onto the shop floor. This generates fugitive dust. These sources can be locally hooded, but normally are not.

Other sources of pollution are those associated with the disposal of solid waste from the process. The first results from the transportation and disposal of the BOP dust. Unless closed containers or trucks are used, the act of transporting the dust can cause some of it to be re-entrained into the air. If the dust is recycled to the ironmaking process, its disposal does not cause further environmental problems. However, in most BOP facilities, the contaminants in the dust, principally oxides of zinc and tin, may cause serious problems in the blast furnace. Rather than recycle the dust, the operators find it necessary to either "store" it on the ground in the open or dump it in a landfill. In either case, special precautions must be taken to prevent the winds from picking up the dust and re-entraining it into the air or the rains from leaching out toxic compounds from the dust and delivering them to the underground aquifer or the nearby water course.

The second source results when a portion of the slag which is removed from the BOP vessel is utilized. In a separate facility, metallics are recovered by magnets and returned to the steelmaking operations. Some of the slag, because it is relatively low in sulfur and high in lime, may be charged into the blast furnace. The remaining slag is disposed of in the landfill. As with the dust, special care is required to avoid the adverse aspects of leaching.

Water Pollution

There are no direct sources of water pollution within the process. Such water pollution sources as may exist result from the particular type of fume collection system employed. If a scrubber is used, there is discharge of scrubber water. Normally, most of this is recycled through a clarifier; however, facilities are required for dealing with the necessary blowdown to the water system. Even the dry precipitator may result in a discharge of contaminated water. This results from the final step in gas cooling, which is the quenching and conditioning of the gases by means of water sprays. If the quantity of water used in conditioning or its method of application is not carefully controlled, there is an overflow of water from the conditioning process which is contaminated with BOP dust and must be treated.

3.0 CONTROL TECHNIQUES AND EQUIPMENT

The various sources of emissions from a BOP furnace shop were addressed in Section 2.4 of this manual. In this section, the various techniques and equipment used to control these emissions sources will be discussed.

3.1 EMISSION STANDARDS

Table 1 shows the current standards for air and water pollutant emissions established by the Environmental Protection Agency. The standard for particulate emissions applies only to new or modified units on which construction was begun after June 11, 1973.

TABLE 1. EMISSIONS AND EFFLUENT LIMITATIONS

	BOP			
	Dry	Semi-Wet	Wet	
New Source Air Standard[4] - Particulates mg/scm dry	50	50	50	
Effluent Guideline Existing[5] Sources			Max. 1 day	30 day average
Total Suspended Solids - kg/metric ton of steel		zero discharge	0.0312	0.0101
pH			$6.0 \leq pH \leq 9.0$	
Effluent Guidelines New[5] Sources				
Total Suspended Solids - kg/metric ton of steel		zero discharge	0.0156	0.0052
pH			$6.0 \leq pH \leq 9.0$	
Fluoride - kg/metric ton of steel			0.0126	0.0042

Two sets of effluent limitations are applicable. One set applies to all new sources on which construction was begun after February 19, 1974. The other set applies to existing sources as of that date. More stringent limitations on existing source effluents are scheduled to be implemented in 1983.

The individual states or municipalities may or may not have standards more strict than those cited in Table 1 both for new and existing sources. Because of the large number of jurisdictions involved and various bases for these standards, no compilation has been attempted for this manual. The reader should refer to the particular area of interest for this information.

3.2 PRIMARY EMISSIONS CONTROL

Primary emissions refers to those emissions leaving the mouth of the furnace vessel. The generic types of control equipment used in the United States to capture particulate emissions from the vessel mouth are scrubbers and electrostatic precipitators. Selection of a control device for the vessel waste gases is interrelated with the selection of hood design for capturing the gases.

Carbon monoxide (CO) is emitted from the vessel mouth during the oxygen blowing phase of the cycle. The gas temperature is sufficiently hot to promote combustion of CO if air is permitted to mix with the waste gas. A design decision must be made to determine how much air, if any, is allowed to mix with the gas, so that hood cooling capacity can be matched to the system needs. Obviously, some air admission is necessary to obtain the capture velocity required to contain fume emissions within the hood.

Many of the early BOP furnace installations used precipitators for controlling particulate emissions. Because of the potential for ignition of CO-air mixtures by precipitator sparking, it was necessary to admit large quantities of excess combustion air at the hood and facilitate complete combustion of CO. This design decision led to having to treat larger gas volumes for control of particulate emissions than is necessary for scrubbers. The treated gas flow rate is approximately 62 scmm per metric ton (2,000 scfm per ton) of steel.

With scrubbers for primary control the risk of explosion is considerably less, but choosing to burn the CO to carbon dioxide still requires the admission of air and consequent gas dilution. The combustion hood gas volumes for scrubber systems are designed for approximately 28 scmm per metric ton (900 scfm per ton) of steel.

More recent plant designs have incorporated limited or partial combustion of CO, thereby reducing the heat generated in the hood and the gas volume to be treated. Careful control of the amount of air admitted to the hood allows ten to fifty percent combustion of CO according to the designer's preference. Gas cleaning now is exclusively scrubbers. The design gas flow rates are approximatley 16 scmm per metric ton (500 scfm per ton) of steel. The advantages of partial combustion are reduced energy consumption for gas cleaning as compared to a scrubber on a full combustion hood, and the potential for recovering CO as a low grade fuel source 7,500,000 joules/scm (200 BTU/scf). Though several plants in the United States are now operating with partial combustion hoods, none of the plants are recovering the CO and the gas must be flared before discharging it to the atmosphere. Plant managers claim that the investment in gas holding facilities is not yet economically attractive (approximate installed cost for new plant with 227 metric ton [250 ton] vessels is $10 million).

Equipment Configurations

Precipitator System Hardware

Figure 4 shows a typical configuration for a precipitator installed on a BOP furnace. Initial cooling of the waste gases is by means of a water cooled hood or waste heat boiler. As mentioned in Section 2.3, some plants use auxiliary fuel firing during the non-blowing part of the cycle to generate a continuous flow of steam.

Cooling is continued by the use of water sprays located in the upper part of the hood. These sprays are generally controlled by time and/or temperature to turn on and off at various points in the operating cycle. The intent is to limit the gas temperature reaching the precipitator and to moisture condition the gases for better precipitation. The maximum temperature of gases entering the precipitator is usually kept under 343°C (650°F).

Following the water sprays there is usually a spark box or chamber to knock out chunks of refractory or other coarse material carried over from the

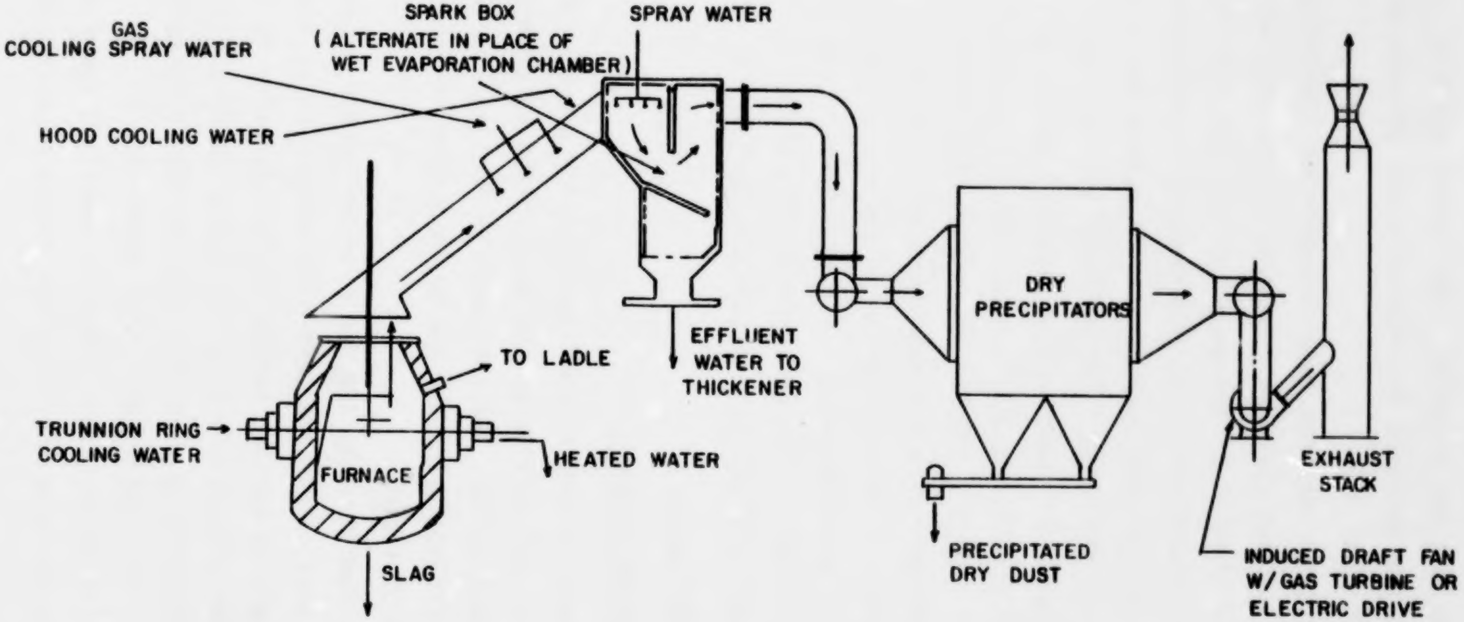


Figure 4. Typical configuration for a precipitator installed on a BOP furnace.

vessel. The spark box is also the point for dirty water separation, if any results from excess water spraying. Some plants operate with essentially no water discharge at this point.

Because the gas temperature is relatively low during hot metal charging and the early minutes of a blow, some plants use steam injection either at the hood sprays or spark box location to achieve the desired conditioning of gases. Water sprays do not evaporate sufficiently under the low temperature conditions and puffs of iron oxide fume are typically observed coming from the stack during this period. Steam injection both at the beginning and end of the heat can eliminate these puffing emissions.

Downstream of the sparkbox the gases are carried to an inlet plenum that distributes the gases to multi-chambered precipitators. On the outlet side of the precipitator there is usually a manifold arrangement that distributes the gases among multiple fans. The preciptators may or may not have spare capacity in terms of an extra chamber or extra collection field in the direction of gas flow. It is common that at least one spare fan is available.

In a two vessel shop, somewhere just upstream of the precipitator inlet plenum, ducts from each vessel join into a common flue. Isolation of each vessel from the precipitator is usually managed by installing guillotine dampers upstream of the junction point. When a vessel is being relined the fans are then drafting only the operating vessel, otherwise much draft is wasted on the non-operating vessel.

Draft and temperature monitoring is normally done at several locations in the system. Sprays are used to control precipiptator temperatures; so the sprays must, to a certain extent, be temperature controlled.

At several locations in the system, suction pressure is sensed and used to control the opening and closing of flow control (louver) dampers. For certain phases of the operating cycle there are specific draft set points that control the evacuation rate of the system. Full system draft is used during hot metal charging and the oxygen blow. Partial draft is used during scrap charge and reblows. There may be little or no draft during the remainder of the operating cycle. Draft is limited when hot gases are not available to prevent too much precipitator cooling. The continual expansion and contraction of hood, ducting, and precipitator is structurally detrimental, resulting in leaks. Corrosion, too, may be a problem for a precipitator if cold air is alternated with hot, moist gas.

Dust removal from the precipitator hoppers is most often done by screw conveyors to some common discharge point. Though there are many operating problems related to the use of screw conveyors, no clearly superior alternative equipment has been found to eliminate their use. Dust removal from the precipitator site is usually by truck to a landfill site.

Whether the landfill is storage or a permanent disposal site depends on the economics of recovering metal values from the dust. At present most plant operators have no plans for the dust because of the presence of zinc in it. Zinc enters the process through scrap charged to the vessel. This metal causes spalling (crumbling) of the refractory lining of blast furnaces, so reinjection into the plant cycle at the sinter plant or blast furnace is not suitable. Numerous schemes have been investigated to recover the zinc and make the iron available for recycle, but to date no U.S. plants have attempted full scale installations of the required process equipment.

Overflow water from the spray chamber or spark box flows or is pumped to a settling tank of some sort and the settled solids dragged out by conveyor. If not recycled, plants generally combine the overflow or the blowdown with process water from other plant areas for clarification prior to discharge.

Some further insight into the pollution control system can be gained by examining typical design data. For a two 227 metric ton (250 ton) vessel shop, the typical gas flow rate would be about 519 actual cubic meters per second (acms) (1,100,000 actual cubic feet per minute (acfm)) at 316°C (600°F) entering the precipitator. The moisture content of the gas stream would be about 30 to 40 percent by volume at this temperature. Inlet dust concentration during the blow would average about 16 grams (g)/scm (7 gr/scf) or about 24.8 g/scm (10.8 gr/scf) dry. To achieve compliance with the New Source Performance Standard (NSPS), 50 mg/scm (0.022 gr/scf) dry, a collection efficiency of 99.8 percent would be required.

On the basis of past practice the precipitator installation might consist of four double-chambered precipitators. The total collection surface required to achieve 99.8 percent would be approximately 91,974 square meters (990,000 ft^2).

Many existing precipitators have much less collecting surface per unit gas volume than this because they were designed for lower efficiencies prior to the new emission standards.

Ideally each chamber would be individually isolatable to permit on-line maintenance, especially for a shop that has no weekly downturn for maintenance. Four fans would be available to serve this installation, three operating and one spare.

For the system with excess water fed to the hood sprays and spark box, the effluent rate would be about 1893 liters per minute (500 gallons per minute). This effluent would be treated in a settling tank initially and then sent to a thickener for solids settling with other process wastewater.

To monitor control equipment operations and furnace draft the following systems' sensors and alarms are used:

Low Pressure Alarms:	instrument air, oxygen supply, lance cooling water, hood cooling water, service water, waste gas duct, clean gas duct, plant air
Low Level Alarm:	hood water cooling tower
High Temperature:	cooling water, dirty gas at precipitator inlet
Failure:	precipitator transformer-rectifiers
Vibration:	for all fans
High Bearing Temperature:	for all fans

Many of the above items also have continuous strip charts to record data, e.g., oxygen supply, water flow rates, system temperatures at various points, system draft at various points. Combustible content of gas or CO concentration is an additional important process variable that should be monitored and alarmed with precipitator systems.

The type of staffing used to operate and maintain precipitator systems varies from plant to plant. One plant producing 32 heats per day, seven days a week has two operator/maintenance people assigned at all times to observe precipitator conditions and inspect equipment for problems.[6] The estimated actual maintenance for the precipitator systems is 75 to 100 hours per week including sprays, dust valves, hoppers, and all things related to the gas cleaning system.

Another plant operating on two shifts daily has no permanent maintenance people assigned to the precipitator, but does required work during the two 4-hour down periods each day.[7] Daily work includes duties such as rodding out differential pressure instrument lines to maintain accurate draft measurements.

Precipitator Startup[6]

Following is an abridged version of startup instructions for an electrostatic precipitator system.

> These procedures should be followed on initial startup and on startup after a lengthy outage. For short outages, the precipitator would normally be deenergized at the power distribution panel and the high voltage disconnects switches, if used would be grounded.
>
> 1. Observe all safety precautions.
> 2. Inspect all hoppers and conveyors to make sure they are clear of accumulated dust and that conveyors operate smoothly.
> 3. On positive pressure precipitators, energize the insulator compartment ventilating system, move the disconnect switch handle to on position, turn the power switch on the ventilating system control panel to on, and press the blower motor start button.
> 4. If high voltage disconnect switches are used, make sure all are at on position releasing power distribution panel interlock keys. These switches are on the roof of the precipitator.
> 5. Check position of dampers in the inlet and outlet flues; make sure the outlet damper is more open than the inlet.
> 6. Start the fan or fans to move flue gas through the precipitator. If both a forced draft fan is used ahead of the precipitator and an induced draft fan after the precipitator, start the induced draft fan first.
> 7. Allow the flue gas to pass through the precipitator sufficiently long to purge the system before energy is supplied to the high voltage system. This lessens the danger of possible explosive gas and air mixtures, eliminates free moisture, and establishes minimum startup temperature of 82°C (180°F) at the precipitator inlet before operation is started.
> 8. Energize the dust removal system.
> 9. Energize the rapper system by turning each chamber rapper control switch on the rapper control or if present the single control switch for all chambers to on position.
> 10. Energize the transformer-rectifier sets.

Precipitator Maintenance[6]

Following are maintenance recommendations for a precipitator system.

Precipitator maintenance procedures daily:

1. Take readings at all instruments, preferably hourly or at least once per shift except on basic oxygen open hearth applications where closer monitoring during blowing cycles is advisable.
2. Make sure all insulator compartments are properly ventilated. Be sure the vents are clear.
3. Make sure all rappers are functioning properly, replace faulty units.

Weekly:

1. Remove dust and foreign matter from electrical equipment.
2. Thoroughly inspect the interior of the precipitator and make necessary adjustment or repairs. Give particular attention to the high voltage electrodes each of which should be centered between the collecting surfaces. Misalignment of even a single unit reduces the electrical clearance between high voltage electrodes and collection surfaces resulting in marked reduction of collection efficiency.

The next section is on maintenance records that are recommended. To aid in maintaining and operating the precipitator, a precipitator operating logbook should be used. The following data should be recorded in it:

1. Air load readings taken by the manufacturer's startup engineer when the precipitator was installed and air load readings taken after maintenance, repair, or inspection.
2. Precipitator condition observed during each inspection such as evidence of dust buildup, bent or burned discharge electrodes, poor alignment, dirty or broken insulators, evidence of corrosion, and all other unusual conditions.
3. All lubrication, maintenance, and repair work.
4. Automatic voltage control readings should be recorded at regular intervals.
5. Describe unusual operating conditions as fully as possible, include date and time at which these conditions occur so that this data can be correlated with the plant operating data.

Scrubber System Hardware--Combustion Hood

Figure 5 shows a typical configuration for a scrubber installed on a BOP furnace with an open or combustion hood. As in the case of the preciptator system initial cooling is via a water cooled hood or waste heat boiler. Also, auxiliary fuel firing may be designed into the system to provide a continuous steam source.

Cooling is continued by the use of a spark box or quencher where grit and coarse particles resulting from refractory and chunks of slag or metal are separated from the gas stream. Quenchers reduce the gas temperature to less than 93°C (200°F) and saturate the gas with water vapor.

From the quencher the waste flows to a high energy scrubbing device where removal of fine particles occurs. The most common scrubber type is a venturi with an adjustable throat. The venturi is opened or closed to increase or decrease gas velocity, i.e. pressure drop through the throat. The flooded disc scrubber is another type wherein opening and closing of an annular space by moving the disc achieves the velocity and pressure drop changes.

An integral part of the scrubbing unit is some type of moisture separating device to knock out drops of water carried out of the throat. This may be a series of baffles or a centrifugal chamber in which the gas is spun to cause the drops to impinge on the chamber walls. Also sometimes used is an after-cooling chamber where cooling water is sprayed to further reduce the gas temperature. At cooler temperatures, moisture condenses from the gas thus reducing the volume of gas to be handled by the fan.

The scrubber systems usually have multiple venturi throats. Two and three vessel shops may have two to six separate scrubbing units in a parallel flow arrangement. As in the case of precipitators, the scrubbers are typically manifolded to a multiple fan installation. Spare fan capacity is available in some installations.

One or two scrubber systems may be shared by a two or three vessel shop. The flues come together into a common inlet downstream of the quenchers. Isolation of non-operating units is important to prevent loss of draft capacity at the operating units. This is accomplished by the use of guillotine dampers upstream of the juncture point.

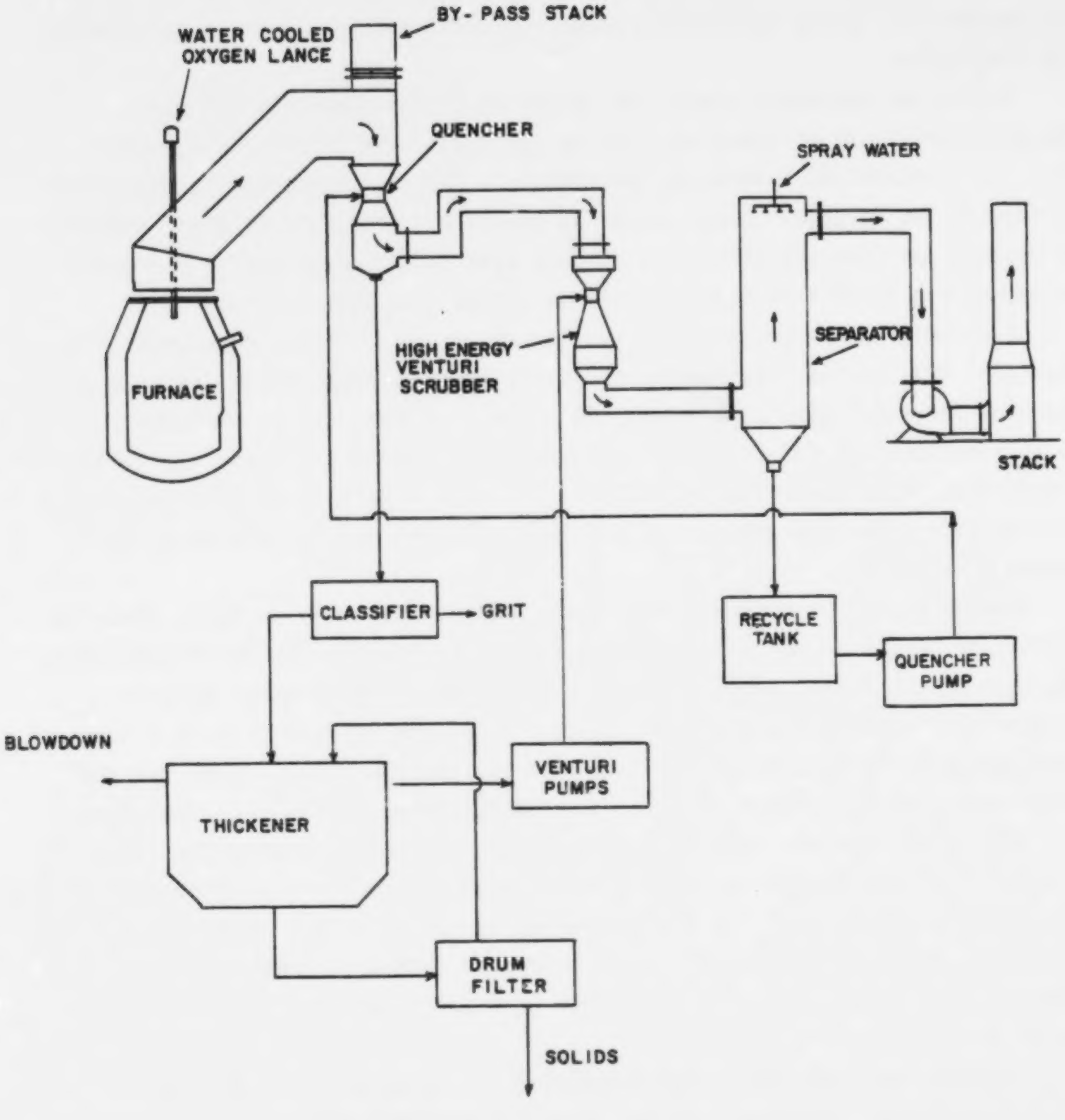


Figure 5. Typical configuration for a scrubber installed on a BOP furnace with an open or combustion hood.

Draft control for the scrubbing system is provided by the ability to vary scrubber throat openings and fan dampers. As in the case of precipitators, temperature and draft are monitored at several locations in the system. The fan dampers are closed to minimize power consumption during certain portions of the heat cycle.

During the hot metal charge the vessel is tilted away from the hood, reducing the amount of fumes that can be captured. The draft or evacuation rate can be maximized (improving the chance to capture some charging emissions) by opening the scrubber throat as far as possible. When this is done, however, it reduces gas cleaning efficiency for any particulates captured in the hood. Practice with respect to these operations varies from shop to shop.

A recycle water system is the typical way in which scrubber wastewater is handled. This system incorporates a preclassifier of some design, a thickener(s), and some thickener underflow dewatering device. Schematically, the "clean" water overflow from the thickener is pumped to the venturi throat. Use of high pressure spray nozzles dictates the need for a relatively clean water supply at this point. This water and solids are separated from the gas stream in the moisture separator.

The water out of the separator flows to a recycle or surge tank. From the tank, part of this water is pumped to the quencher and part to the thickener(s). The used quench water, containing coarse particles, flows through the preclassifier before return to the thickener. There are variations on this flow arrangement as to location of the preclassifier and the recycle tank, but the water supply to the venturi must be the cleanest water available in the system.

Underflow from the thickener(s) is pumped to a rotary drum vacuum filter or centrifuge for dewatering. The cake produced is usually trucked to landfill in an open or tank truck. If the dewatering operation is not sufficiently effective, the tank truck would be the preferred method of transport. The comments made in the precipitator section on recovery of metal values in the solid waste apply in this case as well.

Improved settling and sludge dewatering may be achieved by the addition of polyelectrolytes. Blowdown from the recycle system may require pH adjustment and further removal of suspended solids to meet effluent guideline limitatons.

Recycle water systems typically have problems with corrosion and scaling. Chemical additions are made to control the scaling problems. Corrosion conditions can be improved by pH adjustment or careful material selection.

A further understanding of an open hood scrubbing system can be gained by examining typical design conditions. Just upstream of the quencher the off-gas rate is about 106 scms dry (225,000 scfm dry) for a 227 metric ton vessel (250 ton). Actual temperature conditions at this location would be about 1538°C (2800°F). Through the quencher the gas is saturated and the temperature reduced to about 82°C (180°F) at a volume of 310 acms (650,000 acfm) saturated (approximately 50 percent moisture by volume). On the above basis the inlet particulate concentration would be 35.5 g/scm dry (15.6 gr/scf dry) at the quencher inlet. To achieve compliance with the New Source Performance Standard of 50 mg/scm (0.022 gr/scf) dry, an efficiency of 99.86 percent is required.

Scrubber pressure drops vary widely in practice, ranging from 100 to 180 centimeters (cm) H_2O (39 inches to 71 inches). To reach compliance with NSPS the range of 150 to 180 cm would probably be necessary.[1,8] Water flow rates to the quencher and venturi nozzles would be about 1 liter(L)/scm (7.5 gallon (G)/1000 scf) each.

Monitors and alarms are provided for the following equipment:

Low Pressure Alarms:	quencher water, scrubber water, aftercooler
Level Alarms:	surge or recycle tank
High Pressure Alarm:	drop across aftercooler
High Temperature Alarm:	downstream of quencher
Vibration:	all fans
Bearing Temperature Alarm:	all fans

Interlocks with the oxygen lance prevent oxygen from being turned on without some minimum draft in the flues. Temperature sensors may be tied to the opening of a relief damper in some systems. Water supply failure to the scrubber can shut down the fan(s).

Fan starts may be interlocked with the following system status:

1. quench water on,
2. at least one isolation damper open,
3. scrubber water on,
4. aftercooler water on,
5. manual fan dampers open,
6. flow control louver at fan must be closed (to prevent motor overload during startup).

Staffing for BOP scrubber systems may require two full-time operators, one to attend the gas portion of the system and one to attend the wastewater treatment system. The location of the operators with respect to each other depends on where the control boards for each part of the system are located. Heavy maintenance work, both mechanical and electrical, is usually staffed from the shop maintenance staffs.

Scrubber Startup

Following is a condensed version of startup instructions for a scrubber system.[9]

1. Start cooling water flow to the gas cooling tower and periodically monitor gas cooling water level alarms.
2. Most scrubber units have a classifier of some type to remove larger particles of the highly abrasive solid material that may be carried in the exhaust gases. If not removed, this material can be carried into pumps where the resulting abrasion can reduce the impeller life to a few weeks. The classifier (e.g., rake, screw conveyor, or hydroclone) should be started up at this time.
3. Start the water filter system. Generally the following sequence can apply: sludge hopper vibrator, drum filter agitator, thickener drive motor, thickener rake positioner, thickener underflow pump, drum filter drive, vacuum pump motor, filter air blower motor, and filter filtrate pump.
4. Start quencher and venturi pumps, and the attendant water flow recorders. Pump discharge valves may require manual adjustment to achieve the desired flow rate.
5. Start fan motor bearing lube pump (and fluid drive oil pumping if the system uses fluid drive) and system temperature recorders.

6. Start fan motor. Typically this is a constant speed motor, with the load controlled by adjustment of the venturi throat to allow for variations in the gas flow while maintaining the cleaning efficiency necessary. Scrubbers with a variable venturi throat sometimes are set to close the throat before starting the fan. Others close a fan inlet damper to protect the fan motor during startup. At this time, such pre-start controls are set and the fan is started. (Note: automatic fan shutdown may occur due to high fan vibration, or motor overload). Adjust differential pressure controller and the motor power controller.

Scrubber Shut Down

Shut down is essentially the reverse of the system startup procedure, depending somewhat on the anticipated duration of the shut down. Under a short duration shut down, the main fan is stopped, while lubricant recirculation systems, etc. continue to function. All water clarification equipment must continue to operate. Under a long duration shut down, all scrubber equipment is stopped. Water clarification equipment is operated, however, long enough to purge the system of settled solids. In sub-freezing temperatures, water collection areas are drained or run at minimum water flow to prevent ice formation.

Scrubber Maintenance

Following is a condensed version of recommended maintenance for a BOP scrubber system.[9]

1. Inspection of the quencher area is recommended after each furnace campaign. All water cooling connections to the quencher should be inspected for possible leaks. Quencher sprays should be spot checked for possible spray pipe pluggage. Heavy accumulation of sludge in the quencher elbow should be flushed.
2. The main gas duct between the quenchers and the venturi scrubbers should be walked monthly for an inspection. Any significant solids accumulation should be removed at the time of inspection. Brick linings should be inspected for wear as well and repaired if damage is detected.

3. At convenient periods, and based on operating experience with the equipment, the preclassifier should be drained and cleaned. Daily inspection to observe the operating conditions should be maintained.
4. Hose or pipe connections to individual venturi scrubber nozzles should be checked frequently for leaks and pluggage. Individual valves at each of the nozzles may permit isolation of the nozzles for maintenance during equipment operation. Drive components for the venturi throat should be inspected weekly. The throat drive gears should be lubricated at the time of inspection. Scrubber water manifolds must be maintained free of solids accumulation. Based on operating experience, periodic purging of the manifold lines should be practiced.
5. The internal scrubber throat should be inspected about every three months. Examine the brick lining for evidence of wear. Repair cracked or eroded refractories as soon as possible to prevent further damage and possible damage to the metal shell.
6. Aftercooling towers should be inspected during system shutdown periods. Accumulated solid material in the aftercooling tower should be flushed. The cooling tower spray nozzles should be operated to verify that all nozzles are functioning properly and not worn or plugged.
7. General inspections of the induced draft fans and associated equipment should be conducted daily. The induced draft fans internal components should be inspected weekly. Heavy accumulation of material on the fan wheels should be sandblasted until the fan wheel is clean. Fan wheel sprays should be checked to determine that their operation is satisfactory.
8. Rotary drum filters and their associated equipment should be visually inspected daily. Piping to each drum filter should be maintained free of pluggage. Cake chutes from which the drum filter discharges the sludge must also be maintained free of accumulation.

Scrubber System Hardware -- Closed Hood

Figure 6 shows a typical configuration for a scrubber installed on a BOP furnace with a closed hood. The system closely resembles an open hood venturi scrubber system. One of the principal differences between the two systems is the position of the hood with respect to the vessel mouth. The hood must fit

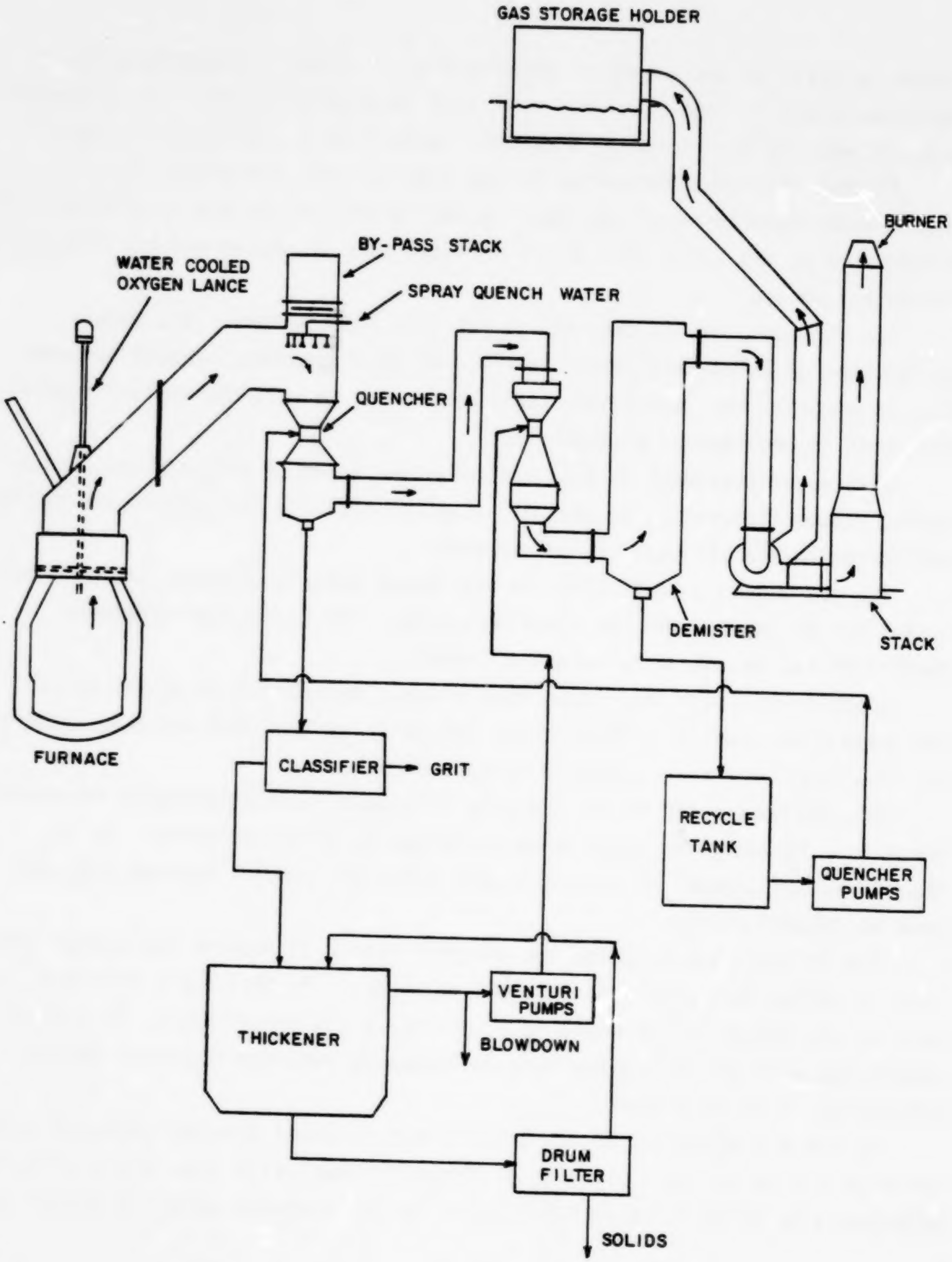


Figure 6. Typical configuration for a scrubber installed on a BOP with a closed hood.

closer to restrict the inflow of combustion air. Since a closed hood would restrict vessel tilting, the hood skirt must be movable or the flow of combustion air must be restricted by some other means than a close fitting hood.

Another important difference is the need to limit the amount of air infiltration downstream of the hood. Normal points of leakage in an open hood system such as the lance port and flux chutes must be sealed and are nitrogen purged before use.

Gas flow sequence is the same as for open hood systems. The water-cooled hood or waste heat boiler is followed by a quencher, venturi scrubber, mist eliminator, fan, and flare stack. There may be multiple venturi throats, but draft is provided by a single fan.

Wastewater treatment is also basically the same. Preclassifiers, thickeners, vacuum filtration, pH control, chemical addition for control of scaling and corrosion are all part of some systems.

The gas cleaning facilities are not shared between adjacent vessels; each vessel has an independent gas cleaning system. The wastewater treatment facilities may be shared by adjacent vessels.

Draft control for the closed hood systems is critical to proper control of the combustion reaction. The systems typically include hood pressure sensors to alter draft via the adjustable venturi throat.

Because hood draft is so carefully limited to near atmospheric pressure, there is a tendency for these primary systems to emit hood puffs. It is, therefore, not unusual to have secondary emissions control systems that are used to control puffs.

The off-gas rate entering the quencher from a 227 metric ton vessel (250 ton) is approximately 59 scms (125,000 scfm) dry. On this basis the inlet particulate concentration would be 32 g/scm dry (14 gr/scf dry). To achieve compliance with New Source Performance Standards requires a control device efficiency of 99.84 percent.

To achieve 50 mg/scm (0.022 gr/scf) dry the total scrubber pressure drop is about 165 to 170 cm H_2O (65 to 67 inches). One system type with a quencher pressure drop of 13 to 18 cm H_2O (5 to 7 inches) captures about 75 percent by weight of the particulate at the quencher. The remainder is captured at the venturi with a pressure drop of about 152 cm H_2O (60 inches).

Operated in the suppressed combustion manner, the waste gas system can recover as much as 62 scm (2,200 scf) per metric ton of steel produced. The heating value of the waste gas is over 7,500,000 joules/scm (200 BTU/scf).

An example of the alarms and interlocks in the closed hood system that are not present in the open hood system is available from a technical paper by U. S. Steel.[10] The following alarms were identified as causing no process shut downs:

1. Increasing negative pressure in the waste gas duct that might pull in water seals and reduce hood draft.
2. High oxygen content in the flare stack. This indicates air leakage downstream of the quencher; 1 to 2 percent oxygen is normal.
3. Ruptured disc at the relief door (for emergency pressure relief) that might let air enter the system.
4. High waste gas temperature (> 1093°C, 2000°F) at the top of the water cooled hood indicates a combustion rate greater than 25 percent.
5. Hydraulic system for the hood skirt malfunctions.

Failures that will not allow a blow to begin, but will not interrupt a blow in progress include:

1. Low water level in relief door seals.
2. Relief door at top of water cooled hood open,
3. Relief door before the venturi open,
4. Relief door before the fan open.

Major faults cause equipment shutdown in the following ways:

1. Local emergency stop, 4160 volt power failure, or fan starter failure cause the venturi throat and fan inlet damper to open to let the coasting fan evacuate the duct. The oxygen lance is raised; the hood skirt is raised; nitrogen seals remain on for two minutes; scrubbing water is stopped.

2. High fan or motor bearing temperature, low fan lubricating oil pressure, or pressing the fan stop button permits the fan to continue for two minutes after the oxygen lance is retracted. Other actions follow (1) above except scrubber water is left running.
3. High waste gas temperature [sic., second stage of temperature alarm], low hood cooling water flow, low waste gas flow, nitrogen purge failure, high hood cooling water temperature, low quencher water flow, or water in the fan inlet allows the fan to continue to run; the oxygen flow is shutoff; nitrogen is shutoff; the hood skirt is manually raised; the gas flow is normally regulated by the venturi and fan damper until the fault is corrected.

3.2 SECONDARY EMISSIONS CONTROL

Secondary emissions are the emissions that escape capture in the primary control hoods and those emissions from ancillary operations in the BOP shop. The typical ancillary operations are described in Section 2.4 of this manual.

The pollutants to be captured during charging, tapping, and puffing of the vessel are those cited previously, mainly particulate, with some carbon monoxide, and perhaps fluorides. Some primary emission control systems, especially those built more recently, include design features to control the vessel secondary emissions. Smaller hoods can be placed over the position of the vessel mouth during charging and tapping. Gas trapped by these hoods is ducted to the main duct leading to the primary system collector. Such an arrangement would be found on combustion hood primary systems where some leakage through secondary dampers is not of great concern.

Charging fume emissions have been reduced in some plants by the use of a Gaw damper in conjunction with the primary collection system. The Gaw damper is a plate that is fitted into the lower portion of a combustion hood. The damper slides horizontally across the hood, limiting flow in some hood areas. During charging the damper is positioned to close off the tapping aisle side of the hood, thus concentrating the draft on the charging side of the furnace capturing more charging emissions. This damper may be especially useful where retrofitting a separate charging and tapping control system is difficult.

Emissions of charging fumes may be substantially reduced by careful attention to operating practice. Maximum reduction is accomplished by two methods. One is to pour the metal into the vessel as slowly as possible. The other is to tilt the vessel as little as practicable, thereby keeping its mouth as far into the hood as possible.

Separate systems may be supplied to control charging, tapping, and puffing. Such systems are more common in shops with a closed hood primary system. Some systems presently in use have gas flow rates in the range of 71 to 94 scms (150,000 to 200,000 scfm). There are no industry wide standards, however. Although the usual control device is a baghouse, in two U. S. plants scrubbers are being used to remove the captured particulate emissions. The configuration of capture systems may be small local hoods or furnace enclosure plus local hoods depending on the designer's preference.

Complete furnace enclosures were initially designed to service Q-BOP installations that must continue nitrogen and/or oxygen blowing while tilting or rotating the vessel. The concept is also applicable to top-blown vessels for fugitive emission control.

Many of the secondary emissions sources are intermittent in nature. Advantage can be taken of this characteristic by combining gas flow from a number of sources and conveying the gas to common or shared collectors. With common fans it is possible to concentrate draft on a single operation for a few minutes and then switch to other sources by means of dampers.

The shared equipment approach has many advantages, but most of the existing plants have added secondary emission equipment as required, resulting in control of one process at a time. Then too, some of the operations are not near enough to one another to accommodate this approach.

Hot metal reladling is one operation often found individually controlled. Early attempts at controlling these emissions were made with multicyclones. The multicyclones could remove kish, but iron oxide penetrated the collector. It is now recognized that fabric filters or scrubbers can be used to collect these emissions at high efficiency. With fabric filters some kind of knockout chamber or spark box is needed to prevent hot sparks from entering the baghouse and burning holes in the bags. For a close fitting hood the gas evacuation rate is about 50 acms (106,000 acfm) at 49°C (120°F). Canopy hoods in place of a tight fitting hood might require three times this volume for effective capture.

One or more flux handling systems are found in BOP shops. Secondary emissions are generated at the railroad car or truck unloading stations, at all conveyor transfer points, and in the storage bins above the BOP furnace. One recently built plant has a 25 acms (75,000 acfm) system with a baghouse for flux truck unloading.[11] In addition there are two flux handling and flux storage bin control systems using baghouses with gas flow rates of 12 acms (25,000 acfm).

Plants making alloy steels with toxic alloying elements have fume control systems for these operations. Leaded steel, in particular, is an example of this situation. The same plant cited in the above paragraph has a secondary control system controlling fumes from the station where lead is added to the ladle, at the teeming stand. The system gas flow rate is 28 acms (60,000 acfm) and particulate is collected by a fabric filter.

Secondary System -- Maintenance

Fabric filters are used frequently in the control of secondary emissions as is suggested by the above discussion. The amount of maintenance required depends to a great extent on how well the system is designed. Proper fabric selection, air-to-cloth ratio, and bag spacing are important. If not properly selected, they will cause frequent replacement or unacceptably high pressure drop. Construction with a spare compartment in addition to the one down for cleaning at any moment permits on-line maintenance. On some installations where the use of the baghouse is intermittent, a spare compartment for on-line cleaning is not required. An example of this situation is the baghouse which serves the reladling station.

Data gathered through plant visits and discussions with control agencies suggest that many secondary systems do not receive as much preventive maintenance and consequently suffer complete failure more often than primary systems. The systems may also be underdesigned and/or equipment with poor reliability may be purchased.

4.0 ABNORMAL OPERATING CONDITIONS

In the following sections are discussions of the AOC's related to BOP shops, broken into a group related to process problems and a group related to pollution control equipment. The importance of each of these AOC's in terms of environmental effects is not necessarily indicated by the length of discussion. Simple descriptions of problems that produce serious effects are possible while less severe problems may require more elaborate explanations.

4.1 PROCESS RELATED

4.1.1 Startup

For the purposes of this manual, startup will be defined to include bringing a new vessel into service or restarting a cold vessel. It will not include the cyclic nature of the basic oxygen process that could be interpreted to produce a startup with each new heat. No special emissions problem has been found to occur in the restart of a cold vessel.

Burn In

This is a situation related to bringing a new or newly relined vessel into service. The vessel is lined with tar bonded refractory. Tar bonding after heating, leaves a residue of tough coke around and between refractory grains to bind and protect the grains. It makes reactions between slag and refractory more difficult thus promoting longer vessel lining life.

To burn in a vessel, a load of coke is dumped onto the bottom of the vessel. Another load of burning coke is added and the oxygen lance is actuated to speed up the burning process. The fire ignites the surface tar near the vessel bottom and gradually moves up the vessel walls as the oxygen lance is raised.

It is necessary to complete the burn in rapidly as opposed to gradual heating to avoid slumping of the refractory lining. The process generally occurs over a time period of 20 to 100 minutes. Vessel reline frequency is related to whether the shop is at full production, the type of steel produced, refractory maintenance practice (gunning), and refractory material. Lining lives in excess of 1,200 heats are not unusual. Some new plants achieve up to 2,000 heats. As recently as five years ago, 500 to 600 heats was typical and could now be found in some instances.

The problem resulting from burn in is the production of carbonaceous fumes or incompletely burned organics. The emissions from this operation are, in some cases, put through the primary fume collection system. Scrubbers can treat the gases; how effectively is not known. Use of primary collectors is the only method known for minimizing emissions.

4.1.2 Shut Down

When a BOP vessel is taken out of service, the lining is broken loose. After completing the breaking operation, the lining is dumped on the ground by rotating the vessel. This usually causes a cloud of dust. Its frequency is the same as vessel burn ins.

4.1.3 Abnormal Operating Conditions

Puffing at Hood

Puffing at the hood refers to escape of fume from the area between the mouth of the vessel and the hood face; although if the hood is not well maintained, fume loss can occur at cracks between the hood panels. Puffing is produced by waste gas pressure surges that the hood draft cannot contain. An inadequate gas removal rate from the hood is one potential cause. However, where initial system design provides a removal rate sufficient to control fume but subsequent deterioration occurs, the cause may be leaks in the hood.

In an open hood system, these leaks may develop between adjacent hood panel sections and are produced by the continual expansion and contraction of the hoods during a campaign. Leaks at points in the gas cleaning system such as expansion joints or duct walls would have the same effect, i.e., reduce draft available at the hood face.

If maintenance practices include complete repair of leaks during vessel relines, it follows that hood puffing from this cause will be of low frequency after reline and get progressively worse as the vessel approaches the end of a campaign. Puffing, however, can occur even on a well drafted furnace when furnace reactions become more active than usual. Foaming and slopping of the bath (discussed later), for instance, can produce puffs.

In a closed hood or suppressed combustion waste gas system, air intake must be carefully limited to prevent more CO combustion than that for which the system was designed. Therefore, the draft at the vessel mouth is controlled to be slightly negative by a sensitive pressure control circuit. Sudden surges in vessel reactions make these systems more prone to puffing. For this and other reasons, suppressed combustion systems should be equipped with secondary fume removal systems.

The frequency of puffing is highly variable from plant to plant depending on the design of the gas cleaning system, its condition, and furnace practice. Puffing can last from a few seconds to an entire oxygen blow (about 20 minutes). No measurement of particulate loss from puffing has been reported in the technical literature reviewed. The quantity per heat would be variable with the severity of the problem.

Recommendations for minimizing puffing due to foaming and slopping and hood or duct leaks are discussed later in this manual under those specific sections.

Improper Transfer of Hot Metal to Vessel

Charging is a routine part of BOP operations, therefore, charging emissions cannot be viewed as an AOC. Charging emissions are fugitive emissions presently regulated only by limitations on the opacity of visible emissions.

There is, however, good operating practice by which charging emissions (hot metal addition to the vessel) can be minimized. Departure from this practice can be viewed as an AOC. To achieve the highest degree of control possible, it is necessary to control the vessel tilt angle and the speed of pouring hot metal.

Minimizing the tilt angle of the vessel keeps the mouth of the vessel closer to the main fume hood (or secondary hood where a charging control system is present). The closer to the hood the more effective is the hood draft in capturing fumes. Since the capture velocity produced by the hood is about inversely proportional to the square of the distance from the hood face, small decreases in the distance between hood and vessel mouth can produce big improvements in capture efficiency and vice versa.

Slow pouring apparently reduces the agitation of the bath and splashing. The severity of charging emissions can also be related to other variables such as charge material and scrap preheating. This will be addressed in a succeeding item.

The frequency of excessive charging emissions can vary widely. The skill of the charging crane operator for instance is important to this AOC. The duration of the emissions can be anything from 1 to 3 minutes per heat. The question of the excess quantity of emissions cannot be answered at this time because the quantity of normal charging emissions is not well defined.

Slow pouring reduces the level of emissions. A hot metal pour of two minutes or longer effectively reduces pouring emissions.

Improper Charge Material

Deviations of hot metal composition and extraneous matter in the scrap are responsible for this AOC. In particular, oil, water, or cement in the scrap are capable of producing increased emissions. The emissions occur where hot metal comes into contact with the contaminated scrap. Hot metal having a high silicon content (>2%) produces increased emissions during pouring.

A rough estimate of the frequency of occurrence is two per week. The duration is that of typical pours or about 1 to 3 minutes per heat. No quantitative data defining the level of increased emissions is available.

Improved control of raw materials and quality of hot metal must be achieved to reduce frequency of this AOC.

Foaming and Slopping

Foaming and slopping describe an AOC in which material from the bath spills over the mouth of the vessel, down the sides, and/or onto the operating floor. This AOC occurs during the oxygen blow while the bath is active due to the various chemical reactions taking place. Spilled material releases iron oxide fume that carries out through the roof monitor.

Often accompanying the spillover is an excursion in the waste gas temperature that may cause a relief damper in the waste gas system to open. The latter problem occurs primarily in systems using electrostatic precipitators for particulate emission control. Precipitator systems are vulnerable to temperature damage because of limitations in the gas cooling and conditioning equipment.

The occurrences of foaming and slopping or perhaps the severity of it seems to have declined as compared to the earlier years of BOP furnace steelmaking. This may be partially related to improved process control which developed as time has progressed.

Several things have been identified as contributing to foaming and slopping problems. The presence of unusually high amounts of silicon and/or manganese in the hot metal charged to the vessel is one factor. In this case, more iron is oxidized and the slag becomes overly oxidized.[12] Later in the heat, the oxygen in the slag begins to react with carbon. Combustion of the additional CO in addition to that produced by lance oxygen increases the waste gas temperature and carbon dioxide (CO_2) content. In a precipitator waste gas control system the relief damper may open with the sudden temperature rise.

When too much oxygen reacts with the carbon too rapidly, the amount of iron oxide formed is insufficient and the slag melting point increases.[12] Solidification of slag compounds stabilizes the foam. The stable and viscous slag leads to spark emissions and vessel slopping.

Slopping is reported to be more prevalent when vessel linings are new.[12,13] This is presumed to be related to the fact that the working volume of the vessel is smaller when the lining is new and thus easier to overflow.

The estimated range of durations for vessel foaming and slopping is one to five minutes. At best, it may occur twice per week. Some shops seem to be prone to the problem. One plant reported two per day average and up to 25 percent of heats could be affected by foaming and slopping.[14]

In response to frequent problems with this AOC, Ford Motor undertook a study to define the problem and find a solution.[12] They found that by adjusting the operating practice they could reduce the frequency of foaming and slopping.

Their solution included continuous monitoring of the waste gas concentration of CO_2. During normal heats CO_2 evolution was found to increase steadily as the blow proceeded, reaching a plateau about ten minutes into the blow. With sloppy heats CO_2 evolution deviated from the gradual increase normally found. Adjustment of lance height and blowing rate were used to maintain the proper rise in CO_2 concentration.

The Ford study cited three variables that had a major effect on maintaining the proper rise in CO_2 concentration. They are:

1. nozzle design,
2. nozzle wear or erosion, and
3. lance height and oxygen blowing rate.

During a heat they found slopping could be reduced by the following steps:

1. "To increase the decarburization rate (rate of formation of CO_2), lower the lance and/or increase the oxygen rate."
2. "If an early plateau in the curve [sic., blowing time versus CO_2 curve] cannot be corrected within one or two minutes by actions indicated above, decrease the oxygen rate to avoid driving excessive amounts of oxygen into the slag and lower the lance to maintain penetration."
3. "To decrease the decarburization rate, raise the lance and/or decrease the oxygen rate."

All of the above steps were used to control the rate of CO_2 evolution, and thus cause the blowing time versus CO_2 curve to follow the path it follows in a normal non-slopping heat. Accomplishment of these manipulations in an effective manner depends on the skill of the operators. Ford reported a wide variation in the ability of operators to reduce slopping. Overall, however, they reported that with good training and supervision they felt they could reduce occurrence of sloppy heats by 90 percent.

All of the above cited experience is for conventional, top blown BOP furnaces. Q-BOP operations are reported to effectively prevent slopping by injection of powdered lime with oxygen through the tuyeres.[15]

Relief Damper Opening

Many BOP furnace systems have relief dampers in the gas system downstream of the water cooled hoods. The purposes of these dampers include pressure relief, temperature protection for the downstream gas cleaning system, and a means of drafting the furnace hood in case of failure or shutdown of the gas cleaning system fans that provide the induced hood draft. When open these dampers release furnace emissions directly to the atmosphere.

The necessity of having such a damper to serve the latter two purposes, i.e., temperature protection and emergency draft, is not certain. Temperature protection of the gas cleaning systems can be accomplished by reducing blowing rate or retracting the lance should a temperature excursion occur.

The need to complete an interrupted heat is certainly a necessity if the metal may solidify before the malfunction can be corrected. In most cases the delay is not long enough to have to finish the heat without control. It can be vented, however, into the building roof and consequently emitted through the roof monitor as is done in plants without the damper. The argument in favor of this approach is that leaks commonly develop because of dirt on the damper sealing surface. These leaks would be avoided where the damper is closed off or excluded.

Emergency pressure relief is a necessity, but can be accomplished with a relief port covered by a rupture disc. This is the kind of equipment used in a suppressed combustion gas cleaning system to prevent leakage during normal operations.

Causes of relief damper opening are combustible gas (in a precipitator system), pressure relief, temperature excursion, and failure of the draft system. The draft system failures will be discussed later in the control equipment section.

The situations in which pressure relief is necessary are not clear. Explosions do occur during charging when the vessel is tipped, but presumably this could also happen on a delayed basis while the vessel is upright owing to water or other foreign material in the charge or a hood water leak. In a partial or suppressed combustion system, carbon monoxide is a potential explosion source if air becomes mixed with it, so great pains are taken to prevent inleakage. In a full combustion hood all carbon monoxide should be burned; but if it is not, it represents an explosion threat when coupled with an electrostatic precipitator.

Temperature excursions can be produced by the vessel reactions that produce foaming and slopping as described previously. Failure of the cooling and conditioning sprays for a precipitator installation would likewise produce an excursion.

The frequency of relief damper openings has been estimated at one to ten per month. Durations could be as little as 20 seconds to as long as the whole blowing time (about 20 minutes). The short duration would probably relate to temperature excursions while the longer duration would likely be related to equipment failure.

Based on data cited in the literature[1,2,3] the uncontrolled emission rate of particulate is 6 to 20 kg per metric ton (12 to 40 pounds per ton) of steel produced. If the relief damper is open for a complete blowing cycle, this would be the emission rate. If only a portion of the blowing cycle is included, the emissions are not directly proportional to the fraction of blowing time. Emissions are higher early in the heat and taper off as the heat progresses. A study[1] performed in West Germany of one furnace showed the dust emissions two minutes into the blow to be 125 g/scm. The dust concentration tapered off nearly linearly until 16 minutes into the blow it was 40 g/scm. These concentrations are not necessarily representative of all types of BOP furnace operation, but demonstrate the decrease in dust emissions as the blow progresses and provide a means for roughly estimating uncontrolled emissions at a given moment.

In the above discussion several means of reducing or minimizing the occurrence of relief damper openings have been mentioned. Some plants with relief dampers in their original gas cleaning system have permanently sealed them. As pointed out, the function of pressure relief can be handled in other ways, i.e., doors covered with rupture discs and doors which open only under pressure surges.

Temperature excursions can be sensed and then alarmed and/or tied into reduction of blowing rate or lance retraction to prevent damper opening. Lance retraction would be reserved for the more serious problems and actuated as the second stage of a two stage sensing system.

Another potential solution is to make the precipitator less sensitive to short term excursions thus permitting continued operation without damper opening except under extreme circumstances, e.g., 800°F for 15 minutes or more. Performance of the collector may be poorer at higher temperatures, but some collection is better than no collection. The primary considerations are insulators and steel expansion.

Porcelain high tension insulators are not used in service over about 450°F. In precipitators designed for continuous service over 500°F and as high as 850°F, alumina insulators are normally used.

If the precipitator has not been designed for continuous service over 500 to 600°F, there may not be sufficient provision for expansion during an excursion to higher temperatures. This could result in permanent deformation of supporting members. Obviously little can be done after the initial structural design is completed, however, a short term excursion may be tolerable. Five or ten minutes flow of hot gas is not long enough to heat the great mass of precipitator steel to the same temperature as the gas stream. Heating occurs gradually, therefore, expansion occurs gradually perhaps providing a short period during which high temperatures can be accommodated without damage.

At the least a change to high temperature insulators will make the precipitator operable at higher temperatures. The equipment designer can be contacted to determine how long an excursion can be tolerated from a structural standpoint.

The presence of a combustible gas mixture can be treated by stopping the blow long enough to clear the system without opening a relief damper. As previously mentioned, if it is necessary to complete a blow to get the metal out of the vessel, it can be done without a relief damper by venting through the building with proper precautions to protect people working the upper building floors, or preferably the heat may be dumped.

Pit or Charging Explosions

These explosions occur in the slag pit or in the vessel. They are generally caused by water getting into the pit or vessel and having molten metal dumped on top of the puddle. The water flashes to steam causing an explosion which throws molten metal or slag randomly around the shop.

The explosions usually shake the building sufficiently to stir up settled dust resulting in some dust emissions from various building openings. Most of the effect is internal and may include serious injury or fatality of workers in the vicinity of the source.

If the vessel is tilted down to receive the charge, the metal is expelled across the charging aisle. If it is tilted up and under the hood, the surge could open pressure relief doors in the gas cleaning system as well.

Pit explosions are estimated to occur three times per year and charging explosions once per year. The explosion is momentary, but may produce effects lasting up to 20 seconds.

The only recommendation for reducing these occurrances is to avoid hood water leaks and any other water spills. Unfortunately, water in the vessel may enter with the scrap.

Running Stopper

Steel from the BOP furnace vessel is tapped into a steel ladle upon completion of the heat. The ladle's function is to carry the steel from the vessel to either ingot molds or, in the case of continuous casting, to tundishes. Molten steel is transferred through a pouring nozzle in the bottom of the ladle. Flow of the molten metal is regulated--on, off, and speed--by movement of a stopper rod whose tip is inserted into the base of the nozzle. The stopper rod head is made of a hard clay-graphite mixture and mates with the nozzle seat made of heavy-duty fireclay.[16] The fireclay softens under molten metal temperature conditions giving a good seal in combination with the hard rod tip.

The causes of a running stopper include an improperly set nozzle, i.e., a rod not mating well with the nozzle seat because of improper installation, teeming a cold heat that leaves a skull at the nozzle seat, and high FeO slag.

The consequence of a running stopper is having steel spill onto the ground in the teeming aisle, reducing product yield, evolving iron oxide particulates, and stirring up pit dust, the latter two of which may escape through the building doors or roof monitor.

Estimated frequency of occurrence is one to three per month lasting from 30 to 60 minutes. No emission measurements of this source alone have been reported. Slide gates are known to have fewer leaks than stoppers, but poor ingot surface conditions may result from using slide gates; so slide gates cannot be used for casting all types of steel.

4.2 CONTROL EQUIPMENT RELATED

There are usually several pollution control systems operating in BOP shops as discussed in Section 3.0 of this manual. Most of the systems have common features, i.e., ducting, fans, monitoring devices, and one of the three generic types of control devices. Therefore, many of the AOC's are common to more than one of the systems. Where a listed AOC occurs in only one of the systems, the narrative will provide this information. Where it is more prevalent in one of the systems, it likewise will be stated in the narrative.

The bulk of data obtained was in reference to the primary particulate control system for two reasons. One reason is that secondary emission control is far from universal, and therefore, a lesser amount of data exist. The second reason is that the visual and production impact of failures in the secondary systems is less evident than primary system failures. For instance, a flux handling dust control system is prone to maintenance problems due to duct buildups of lime dust. The dust control system is not essential to continuing production and is usually located where there are few employees. The result is it receives less attention and less maintenance (though it may need more), and therefore, less data is available concerning its malfunctions. Where the secondary systems are similar to the primary system one may extrapolate that similar AOC's may occur in both systems.

4.2.1 Startup

Here again, as in the case of process startup, startup excludes the normal cycling accompanying the production of each heat. Startup would include bringing the system on-line after a shutdown for maintenance, rebuild, or strike, and bringing a new system into service.

Precipitator Warmup

Most precipitator manufacturers recommend not energizing the precipitator until the gas temperature entering the precipitator has reached 150 to 200°F. Some prefer to have the unenergized condition remain for some time after this point to allow the collecting plates and wires to reach these temperatures. The intent is to drive off moisture which tends to condense on the internal surfaces. Condensed moisture is a problem for two reasons. On the collecting plates and wires it may cause dust collected on it to cake leaving a layer not removable by normal rapping. Secondly, the frames that support the discharge electrodes (wires) are stabilized by insulators that attach to the grounded walls of the structure. Moisture on these insulators will cause dust to stick providing a conductive path across the insulator. This "tracking" can burn out the insulator, thus grounding a section of the precipitator until it is replaced.

Startup of an entire precipitator installation does not occur often, perhaps once every year or two to as little as once in five or ten. More frequently a single chamber of a multichamber precipitator will be taken down for maintenance and restarted. This could occur as often as once per week to once per month. The warmup period is relatively short for the BOP in that the gas temperature reaching the precipitator rises to 260 or 315°C (500 or 600°F) by the middle of the blowing period. Including the charging period the duration is estimated at 10 to 20 minutes.

The impact of the warmup period is varied depending on whether a full or partial precipitator is involved. Obviously, if a whole installation is involved all the particulate matter discharged from the process will be emitted during this period. If only one chamber out of a N-chambered precipitator is involved, about one Nth of the total process particulate will be discharged in addition to the emissions that normally escape the operating chambers. The uncontrolled process particulate discharge rate is in the range of 6 to 20 kg per metric ton (12 to 40 pounds per ton) of steel produced.[1,2,3]

If an unenergized warmup practice is followed, emissions may be reduced by energizing immediately upon startup at a reduced secondary voltage level. Operation at reduced voltage means that collection efficiency will also be reduced, but better than no collection. Reduced voltage, however, reduces the potential for burning out insulators. One potential problem with this approach is the buildup of dust (or mud because of moisture) on the plates and wires. If the moisture condensation is severe, then this is not a satisfactory solution. In some cases increased rapper (or vibrator) intensities may be capable of preventing buildups.

One plant following this practice of reduced voltage energizing has found that 60 percent of the normal operating voltage gives them good results, i.e., no insulator damage and partial collection.[18] Certain types of electrical control sets make operation at these reduced voltage levels on a temporary basis more difficult. Most new sets are solid state devices that can accomodate reduced voltage operation. Older electrical sets, particularly those with saturable reactors, do not work well under these temporary conditions.

Some plants may find they can operate during startup (without warmup) with no serious consequences. Experimenting on one chamber reduces the risk involved.

Preheating the precipitator is another means of minimizing warmup emissions. Use of natural gas just to preheat the precipitator is wasteful from a fuel economy standpoint, but some shops practice scrap preheating in the vessel with natural gas. Scrap preheating in this manner increases the percentage of scrap that can be charged to the vessel. Precipitator preheating then is a byproduct of the production operation.

Design of precipitators with individually isolatable chambers permits on-line maintenance of these chambers and would avoid the need to shut down the whole precipitator for maintenance. As a result, the need to put a whole precipitator through the warmup period would be reduced in frequency.

Stack Puff

Stack puff refers to a temporary increase in particulate emissions, visually recognizable, leaving the process stack. There are stack puffs resulting from continuous operating problems, but stack puffs during startup are caused by particulate lying on the duct floor or attached to flow control louvers in the system reentraining into the gas stream. During a fan or system shut down dust being conveyed by the gas stream settles onto the duct floors. Also, where a single fan in a multiple fan system is shut down, dead or low flow areas may develop in some duct runs leaving dust on the duct floors and flow control surfaces. Upon restarting the fan, the settled dust begins to sluff into the gas stream.

The effect of this action is the greatest when the deposits are downstream of the collecting device where no chance to collect the dust exists. It also occurs upstream of the collector in which case the net effect is minimized by the collector.

The frequency in a multiple fan system can be as often as once per week, to as little as once per year in a single fan system. The duration of the puffs is widely variable. An estimate is one to sixty minutes. No data or estimate of the extent of additional emissions is available.

No good corrective action for this AOC can be recommended. If dust dropout in the flues is an extensive problem occurring during normal operation, it is periodically (perhaps once per year) necessary to remove the dust to prevent overloading of the duct structures. Since the dust is deposited under normal operating circumstances, it cannot be stated certainly that dust emissions upon startup would be any less than had the flue not been cleaned.

Unbalanced Flow Among Manifolded Fans

This is a startup problem peculiar to systems with multiple fans in a parallel flow arrangement inducing draft through a common precipitator. The startup referred to is that of a single fan when the other system fans have been in operation. This would occur when one of the other fans is shutdown as a result of a failure, or for scheduled or unscheduled maintenance.

Maintaining an even flow distribution among chambers of a precipitator is essential to maximizing particulate removal efficiency. In a manifolded fan system, fans tend to draw more gas from the chambers closest to them (path of least resistance) than those farther away (in a well designed flow system this tendency can be minimized by proper plenum sizing and the use of gas distribution devices). Flow control dampers may be located at the outlet of each precipitator chamber and balance restored manually, but the process is time consuming. After some experience it may be possible to reduce this time by having set points marked for the various possible fan combinations.

The consequences of unbalanced flow is reduced total collection efficiency for a number of reasons. Though a volume increase in one chamber is offset by a volume decrease in another chamber, the efficiency changes do not average out because gas flow rate is exponentially related to efficiency. The overall effect is reduced efficiency. Higher gas flow in one chamber may induce reentrainment of dust from the collecting plates, but the corresponding lower gas flow in the other chamber(s) does not necessarily produce correspondingly less reentrainment.

An additional consequence of unbalanced flow is preferential deposition of dust in hoppers under the precipitator chamber with higher gas flow. This can lead to upsetting the hopper dust removal cycle at the least, and, in some cases, may shut down a portion of the precipitator above the problem hopper because of collected dust contacting the discharge electrode frame.

Reestablishing balance in the system was estimated at 12 to 16 hours in one plant affected by this problem.[6] The frequency of occurrence could be as often as once per week to as little as once per year. The practice of preventative maintenance on the fans, however, would typically require more frequent shutdowns than once per year.

The amount of additional emissions resulting can be estimated only if the percentage of gas flow through each chamber is known and the efficiency of the precipitator under normal even flow conditions is known. The emissions can be highly variable from one startup to the next. For instance, in a four fan system where only three operate at any given time, there are four combinations of three fans possible. Each of these combinations can produce different initial flow conditions.

Insufficient Draft

This is an upset that occurs in a control system with common multiple (manifolded) fans. The control device(s) may be precipitators or wet scrubbers in an open or combustion hood type system (manifolded fans in a closed hood system are not typical of present design practice).

Insufficient draft results from one fan being shut down with a simultaneous failure of a spare fan to start. In particular, the upset was reported to occur due to ice in the fan housing. Moisture from the process gas stream condensed, accumulated and froze in the housing to a point where movement of the fan wheel was prevented.

When such an upset occurs the reduced draft leaves emissions to spill over into the shop creating building monitor emissions. The blow rate can be reduced to attempt to match the process emission rate, but hood capture will not be as good because the intake velocity at the hood periphery is reduced at lower gas evacuation rates. The quantity of additional emissions can be relatively low if the blowing rate is reduced and high if production is maintained at the normal blowing rate.

Obviously this upset is confined to the winter season. Its frequency of occurrence was not obtained, but it could potentially occur two or three times per winter season. Its duration would be the time required to melt enough ice to get the fan wheel turning, perhaps two or three hours.

Method of minimizing its effect would include reducing the blow rate as previously discussed. The plant reporting this AOC does the necessary maintenance or fan repairs and restarts the fan when the work is completed.[6] The fan is then kept turning at low speed (idle) to avoid the icing problem and can easily be brought up to speed when required to replace a fan in service. Of course, this practice is only necessary in cold weather.

4.2.2 Shut Down

AOC's relating to shutdown refer to those things occurring when a vessel is taken out of service for maintenance or reline, not to the period at the completion of each heat.

Dampers Stuck or Jammed

This AOC can occur in a two or three vessel shop that shares a common gas cleaning system. Each vessel has its own hood and spray chamber (in the case of a precipitator control device) or quencher (in the scrubber case), but at some point downstream of these the waste gas is combined in a single flue. When one of the vessels is shut down for reline, the ducting to the off-line vessel needs to be isolated from the gas cleaning equipment to prevent fan draft capacity from being lost to the off-line hood. This is accomplished with a butterfly or guillotine type damper.

Occasionally these dampers will not completely close or become jammed, thus allowing leaks of ambient air into the gas cleaning system. These malfunctions reduce the draft available to the operating vessel(s).

Failure to close or jamming is produced in several ways. One way is a failure of the electrical actuating and sensing system. Perhaps limit switches or some other component fails. The accumulation of dust on the sealing or sliding surfaces of the damper may also prevent closing or at least reduce the effectiveness of the seal. Butterfly type dampers are prone to the poor sealing problem. This has led to retrofitting guillotine type dampers into existing systems to provide a better seal. The guillotine type, of course, is not completely trouble-free either. The effect of this damper AOC is reduced draft for the operating vessel(s) with consequent spillover of fumes into the building unless blow rate is reduced. The level of increased fugitive emissions from the building monitor is not known and depends on whether the blowing rate is adjusted.

To determine how often this can occur, it is necessary to know the frequency of vessel relines. The AOC, however, does not necessarily occur each time a vessel is shut down for reline. An estimate of the range of frequencies is once per month to twice per year. The increased emissions will continue until blowing rate is reduced or the repairs have been completed. On this basis the expected duration is one to twenty-four hours.

Duration of these AOC's may be shortened by installation of damper position sensing devices to provide immediate recognition of the problem. The frequency may be reduced by the practice of preventive maintenance, e.g., frequent cleaning of sealing surfaces, cleaning and checking of electrical contacts. Installation of more reliable equipment should also be considered.

4.2.3 Abnormal Operating Conditions

Downtime of Primary Collection Systems

Downtime of primary collection systems refers to shutdown of the entire gas cleaning facility for capturing BOP furnace hood emissions. Failure of portions of the system that do not result in entire facility failure are treated in subsequent sections of this manual. Total failure of secondary systems (charging, tapping, reladling, etc.) are treated in the next section.

One source of total pollution control system failure is catastrophic utility failure, i.e., power loss for a section of or the entire plant. Several plants reported this to occur three times per year to once every five years. A power failure that affects both the process and control equipment causes both to shutdown and, therefore, the immediate environmental effect is small. If the failure is selective and only the control equipment is affected, then the vessel will continue to operate subject to interlock protection built into the system. Some plants may finish a blow at reduced blowing rate to prevent the risk of damaging the vessel if the outage will exceed several hours. The emissions escape the building through the roof monitors or through emergency relief dampers. Under these conditions, continued operation of the vessel would be unlikely past the completion of the heat in the vessel at the time the failure occurred. This was the consensus of plant operator's opinions. The effects of the power failure would be limited to the total vessel emissions from the time the failure occurred until the blow was completed, i.e., some fraction of 6 to 20 kg of particulate per metric ton (12 to 40 pounds per ton) of steel.[1,2,3]

It is conceivable to have a power failure that affects only a precipitator without stopping the fans. This kind of upset was not reported by any plant. Plant practice under these conditions would be is unknown.

Pump failure and fan failure due to mechanical or electrical problems can likewise shut down the total control system. Most of the plants visited, however, had installed spare fans and pumps to avoid a shutdown due to a problem with a single fan or pump. With installed spares it is likely that at worst the system capacity to clean or provide draft will be reduced when a failure in one of the operating components occurs. For instance in a system with four fans (three operating, one spare) when one fan fails the spare is started. In the less likely event that two fail, the vessel can still be operated at a reduced blowing rate. For scrubber pumps the analogous problem is reduced scrubbing efficiency instead of reduced draft.

Clarifier rake failure can shut down the scrubber wastewater treatment system. Rake failures are produced by drive motor breakdowns and mechanical failures in the rake drive system. Chunks of material and a buildup of coarse, dense, gritty particulate on the thickener bottom were two things cited as a cause of rake problems. One plant reported rake failures due to rocks in the thickener, presumably thrown in by employees.

Shutdown of the air pollution control portion of the system (scrubbers) may be avoided during a rake failure if the scrubber can be switched from the recycle mode, to a once through mode of operation. If no spare thickener capacity exists or no terminal settling basins are in use downstream of the bypassed thickener, the increased solids content of the water will be about the 6 to 20 kg per metric ton (12 to 40 pounds per ton) of steel cited previously as particulate production rate. Many of the plants visited did have terminal settling basins of some sort that would reduce the amount of particulate reaching the plant outfall.

Reported frequency of rake failures in the plants visited were between zero and two times per year. The length of time required to repair the equipment and return it to service was reported at one to three days. Both increased solids and increased water rates to blowdown result from this AOC unless production operations are suspended during the repairs. The repair operations often require draining the thickener to remove accumulated solids.

Increased emissions resulting from fan, pump, or power failures may be reduced by interlocking the failure sensors with oxygen lance retraction. If the failure is one that is expected to prevent normal operation for a period long enough to damage production equipment, then the interlocks can be overridden and the blow completed or the heat dumped from the vessel into a ladle for handling much the same as slag.

Installed spare capacity is a powerful tool to overcome the failures in single components. As was mentioned, installed spares are widely used and especially evident in the more recently constructed systems. An exception to this is the fan in a suppressed combustion or closed hood system. In accordance with present design practice there is no installed spare fan in these systems. The concern about air leakage into the system (with the accompanying risk of explosion) is the overriding factor.

Though less effective, the concept of multiple units with no spare capacity is useful. Two units sized for 50+ percent of total capacity leaves the capability for control at reduced efficiency when one of the two fails as opposed to no control when a single 100 percent unit fails. Obviously two units sized for 75 percent capacity would be even more desirable.

In the area of wastewater treatment backup capability, similar concepts are applied to pumps and thickeners. With thickeners, however, an additional alternative may be available through terminal lagoons or settling basins immediately upstream of the plant outfall.

In the way of prevention of thickener rake failures, a number of plants have chosen to install preclassifiers upstream of the thickeners. The commercial forms of the preclassifiers are varied, but their common purpose is to remove grit and heavy solids from the dirty scrubber water thus avoiding its deposition in the thickener. One plant employed a wire screen cover over their thickeners to prevent foreign matter (rocks, etc.) from being thrown into the thickener and consequent fouling of the rake.[19]

Downtime of Secondary Systems

The basic causes of total primary control system failure enumerated in the preceding section are also responsible for total failure of secondary control systems. In addition to those causes, the use of baghouses in control of secondary emissions brings other causes into the picture not present in the primary system (baghouses for primary BOP furnace control are used in Europe, but the first U. S. installation is only now being constructed).[20] The prevalent means for controlling secondary emissions from charging and tapping, hot metal transfer, flux handling, slag raking and desulfurization have been identified in Section 3.0 of this manual. Contrary to the situation with primary emission control, many plants have no secondary emission control systems. Of the listed secondary sources above, flux handling controls are the most common.

As was pointed out previously, power failures may be plant wide or local in nature. Where the failure affects the process as well as control equipment the environmental impact is not significant. The comments on duration and frequency in the primary section apply to secondary systems as well.

Fan failures in the case of secondary systems are expected to be more significant environmentally than in a primary system because spare fan capacity does not generally exist. A single fan failure is likely to mean an entire secondary emission control system will shut down.

Pump failures will affect performance much the same as in primary systems. Wastewater treatment (classifying and thickening) may be shared with the primary control system.

Complete failure of a baghouse can be produced by high temperature or high pressure drop causing a bypass damper to open. Bag blinding due to the presence of mositure or fine fume particle size are possible sources of high pressure drop. Shaker or reverse air system failures may cause a complete shutdown as well as screw conveyor failures depending on where in the system they occur.

If a down turn for maintenance is not provided for the whole shop, maintenance on the secondary emission control systems will mean that the systems must be shut down while the remainder of the shop is running. The environmental effect is the same as though a system failure has occurred.

The limited data obtained on frequency of AOC's on secondary systems indicate relatively high frequencies when compared to primary system AOC's. Data from one charging control system show 28 AOC's over a ten month period.[11] Data from two hot metal transfer stations showed 18 and 47 AOC's over a period of roughly one year.[11,21] Data from two flux handling systems show 1 to 8 AOC's over about a one year period.[11]

No data were obtained for slag raking and desulfurization AOC frequency. One secondary system for teeming leaded steel experienced 17 AOC's over a ten month period.[11]

When an AOC occurs, the environmental effects are periodic. For charging during an AOC, additional emissions occur for about two minutes per heat. Additional tapping emissions are vented for about 4 to 8 minutes per heat. Hot metal emissions occur for about 2 to 4 minutes per heat during a complete control system failure. Slag raking and desulfurization emissions cover a 5 to 20 minute period per heat.

The above data provide estimates of the duration of periodic increased emissions while an AOC is in progress, but say nothing about how long these periodic emissions continue. The length is dictated by the amount of time needed for repairs. Data provided by the Erie County, New York control agency shows repair and maintenance durations for hot metal transfer control equipment to cover the range of 1 to 96 hours.

Literature reference to uncontrolled charging emissions estimate 0.15 to 0.2 kg per metric ton (0.3 to 0.4 pounds per ton) of hot metal poured (approximately 0.13 kg per metric ton of steel assuming 70 percent hot metal charge).[22] Tapping emissions are estimated at 0.08 to 0.1 kg per metric ton (0.15 to 0.2 pounds per ton) of steel in the same source. A second source estimates combined charging and tapping emissions at 0.3 to 0.45 kg per metric ton (0.6 to 0.9 pounds per ton) of steel.[23] Hot metal transfer emissions are estimated to 0.25 to 0.35 kg per metric ton (0.5 to 0.7 pounds per ton) of steel.[22] An estimate of uncontrolled flux handling emissions is 0.75 kg per metric ton (1.5 pounds per ton) of steel based on a material loss of about 0.8 percent during handling.

Precipitator Common

1) Wire Breakage

This is a problem common to precipitators using wire discharge electrodes as opposed to rigid discharge electrodes. The typical configuration of wire electrode is a wire suspended from a frame at the top of a precipitator tensioned with weights at the bottom of each wire. The tensioning weights are about 4.5 to 13.6 kg (10 to 30 pounds) and help maintain the wires in a fixed position between collecting plates. Some additional type of steadying device is provided to keep the wires from swinging with the gas flow. Wire breakage can result from fatigue, corrosion, and electrical stress due to sparking or electrical arcing.

The environmental consequences of wire breakage is increased particulate emissions due to partial failure of the precipitators. When a wire breaks the broken wire generally contacts one of the collecting plates adjacent to it causing the electrical section it is in to short. The transformer-rectifier set supplying power to the section trips. With no power in that section of the precipitator, collection ceases. All the section of the precipitator connected to the transformer-rectifier will be deenergized unless it is possible to disconnect the section with the broken wire and reenergize the remaining sections.

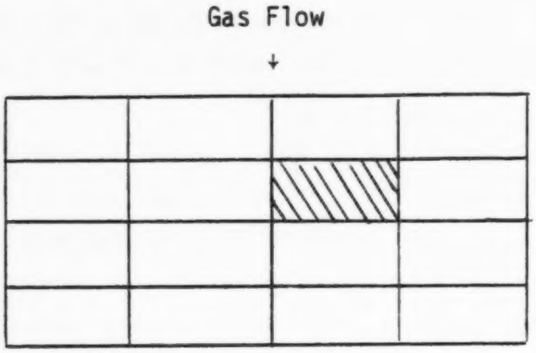
Unless there is a problem with the original alignment of internal components, substandard fabrication materials, or an unusual event like an excursion with corrosive gases, wire breakage tends to be a random event. With a common random failure rate larger precipitators will have proportionally more wires fail than smaller precipitators. The data on wire failures obtained for this study do not indicate the size of the precipitators involved, but some variation in failure rates can be attributed to difference in precipitator size.

Three plants with precipitators serving the BOP furnace reported annual wire breakage of 2, 12, and 200, respectively.[6,7,24] The 200 broken wires is a very high breakage rate and the plant is replacing the transformer-rectifier sets in an effort to achieve better electrical control and reduced wire loss from sparking. Even 12 breaks may be higher than need be experienced.

The duration of section outages caused by wire failures is dictated by the plants' need and desire to repair them. If a shop has spare collection capacity, there is no need to shut down a precipitator or precipitator chamber to repair it immediately. Several may accumulate before a shutdown is necessary. With no spare capacity and isolation capability for each chamber, one chamber may be deactivated and cooled down enough to permit cutting out a broken wire within two or three hours. If a chamber cannot be isolated, the repair must be made when plant operations are curtailed for maintenance.

Cutting out broken wires as opposed to replacement does not cause performance to significantly deteriorate unless they are adjacent wires. Replacement of the cut wires can be made during an annual outage or scheduled maintenance period when more time is available for repairs.

The increase in particulate emissions with a section out of service due to wire breakage can be calculated given the operating efficiency of the precipitator fully energized, total collection surface area, gas flow, and the area of collection surface out of service. Following is an example of the calculation.



Given: Four chamber, four field precipitator
Operating efficiency - 98%
Gas flow rate - 8,500 acmm (300,000 acfm)
Total collection surface area - 12,114 m^2 (130,400 ft^2)
Area not in service - 757 m^2 (8150 ft^2) or 1/16 of the total area

The efficiency of chamber 3 with one field out of service is 94.7 percent obtained by:

1) Evaluate w = migration velocity using the given operating efficiency of 98 percent:

$$w = -Q/A \ln(1 - \text{fr eff}) = \frac{300{,}000}{130{,}400} \ln (0.02) = 9.0$$

2) Using this value of w, evaluate efficiency of the chamber with one field out of service:

$$\text{Efficiency} = 100(1 - e^{-(\frac{24450}{75000} \times 9)}) = 94.7$$

The average efficiency with the one field out of service is 97.2.

$$\eta\text{, average} = \frac{(3 \times 98) + 94.7}{4} = 97.2$$

Particulate emissions should increase by a factor of 1.4

100 - 97.2/100 - 98 = 1.4 times the normal emissions.

This technique can be applied to precipitators with more than one field out of service in several chambers equally well.

Where wire breakage rates are high the alignment of electrodes should be checked to be sure erection tolerances are being met. Sometimes when mass failure occurs the material of construction is found to be inferior.

If high spark rates in a particular section are observed with a high incidence of breakage and the alignment is satisfactory, installation of shrouded wires in place of standard discharge wires should be made. The shrouded wires have protective sheathes at the top and/or bottom of the wire to decrease electrical stresses caused by sparking or arcing. Use of shrouded electrodes in some cases has decreased the frequency of wire failures by a factor of five.

As was mentioned previously in the discussion, heavy sparking may also be caused by the inability of some older type transformer-rectifiers to properly modulate current input. This problem may be eased by use of solid state controls with better controlling characteristics.

2) Sprays Plugged or Corroded

Successful collection of particulate from the BOP furnace by precipitator is dependent on the addition of moisture to the gas stream as a conditioning agent. Without the moisture the particulate resistivity remains high and the collection efficiency is reduced. Demonstration of the effects produced by a lack of conditioning are often evident at the start of an oxygen blow when the stack exhibits more opaque visible emissions than after two or three minutes into the blowing period.

Many of the spray systems are fed by recycled water, so a common cause of spray plugging is solids buildup in the nozzle. The reduced flow area reduces the amount of water atomized and consequently evaporated. Corrosion is also a cause of problems. If atomization is impaired by corrosion damage to the nozzle, the quantity of water going through the nozzle may be sufficient but the amount evaporated will be too little.

The frequency of this AOC is highly variable. In a plant with a regularly scheduled downturn, say once per week, an inspection and/or change may be possible often enough to avoid the problem. One plant reported plugged sprays occur three times per week.[14]

The duration of the problem is as long as it takes to repair or replace the nozzles. With no maintenance, emissions will continue to increase. Some of the plants visited indicated that repair is possible within an hour or two after discovery of the problem. Apparently nozzle manifolds may be interchanged between blowing periods.

The quantitative increase in particulate emissions during this AOC cannot be readily calculated. The fact that the degree of induced conditioning effects is so variable is the primary reason.

To reduce the frequency of this AOC regularly scheduled inspections of the spray systems should be made. The schedule must be more frequent than plugging or corroding frequency to be an effective preventative maintenance program.

The quality of water being fed to the sprays is of prime importance. One plant reported that establishment of pH control and the use of scaling inhibitors in the spray feed water significantly reduced the problems with the spray conditioning system.

3) Insufficient Conditioning of Gases

This AOC is related to the previous one discussed in terms of its effects on precipitator performance. In this case insufficient conditioning results from process conditions (usually temperature too low to activate the spray system).

Water sprays are usually activated on the basis of gas temperatures entering the spray chambers. If for some reason the gas temperatures do not reach the appropriate set points, the sprays will not operate, thus preventing proper conditioning of the gas stream. One problem is a period at the beginning of the oxygen blow when the gas temperature is too low to evaporate the sprayed water, so even if the water is available, conditioning will not occur. Another problem is that process conditions may keep the gas temperature low longer than normal, again preventing proper conditioning.

The lag period, the period when the blow is proceeding but conditioning is poor, may occur with every heat. The duration may be one to six minutes per heat. The increased particulate emissions cannot be readily calculated, but increased visible emissions are observable.

The increase in emissions produced by the lag in temperature after the oxygen blow begins may be eliminated by the use of steam injection during the lag period. Steam provides a source of already vaporized moisture to function as a conditioning agent. Two plants practice steam injection also during hot metal addition and reblows, when conditioning by water sprays is not adequate.[7,24]

4) Corroded Pump Impeller, Pump Failure

The problem with these malfunctions again is inadequate moisture conditioning leading to increased particulate emissions. These malfunctions may completely stop water flow to the conditioning chamber which also allows the gas temperature entering the precipitator to rise. Improper or no pH control or pump motor failures are possible causes.

This AOC was not mentioned as a frequent problem at the plants visited. No estimate of frequency has been made. The duration is until repaired which is estimated at two to eight hours. The quantity of increased emissions cannot be readily calculated.

Possible preventive actions include preventive maintenance and the use of pH control for the spray water.

5) Transformer-Rectifier Set Failure

Transformer-rectifier (TR) sets are the power supplies for the electrical sections in the precipitator. When a TR set fails, the section energized by that TR set is out of service for as long as it takes to replace the faulty set or until a temporary connection is made to an adjacent set. Set failures are typically caused by age and/or overheating. The failure may occur in either of two portions, the transformer, or the rectifier and control portion. The control portion of the unit is the more frequent scene of failures. The newer solid state controls are particularly vulnerable to damage or shortened life from overheating.

The estimated frequency of TR set failures are once every year or every two years. If the failure occurs in the printed circuit cards, it is readily repaired. If the failure occurs in the transformer (rare), it may take a month to obtain a replacement and install it. The range of durations is two hours to one month. The increased particulate emissions can be calculated using the same methodology presented in the wire breakage discussion section.

In a severe area of overheating (in the summer) the room housing the precipitator controls can be air conditioned to reduce failures. The effects of a failure may be minimized by temporarily connecting the failed electrical section to a TR set feeding an adjacent collecting area. The adjacent section may suffer some performance decrease, but the net effect will be improved performance. Because of the time involved in making such a connection, it is probably only justified when replacement is expected to take more than several days.

6) Insulator Failures

Insulators that support the discharge electrode system are subject to failure from cracking or tracking. Failures are caused primarily by dust or moisture deposition on the insulator surface that allows current to track across the insulator and short out a precipitator electrical section. Cracking may be produced by either mechanical or electrical stress.

Failure of an insulator produces the same effect as broken wires or transformer failures. The increase in particulate emissions can be calculated by the same methodology presented in the broken wire discussion.

Data available showed two to four insulator failures per year. Repairs required from one to twelve hours.[21,25]

Insulator failures are best prevented by frequent inspections of the insulator housing pressurizing fan and filter or inspection and cleaning of the insulators themselves where the fan and filter system are not used. For a typical steel plant environment, a pressurizing fan and filter system to supply air to the insulator housing is good design practice.

7) Rapper Failure

Collecting plate or wire cleaning mechanisms fail due to age or low reliability. Failure to remove dust from the electrode surfaces when the plate and wire cleaning systems are in operation may also be due to design deficiencies. Failures of adequately designed equipment can occur either in the control system for the rappers (or vibrators) or in the individual rappers (or vibrators). The latter type of failure is more common. A control system failure will cause a large group of rappers to fail as opposed to individual rapper failure.

The increase in particulate emissions due to rapper failure may result from grounding a precipitator electrical section (because of dust bridging the wire to plate gap) or reduced collection efficiency in that section when the buildup has not reached the point of bridging the gap. If the section is grounded the additional particulate emissions can be estimated by the methodology presented in the broken wire discussion.

The frequency and duration of rapper and vibrator failures is not known. Frequent inspections will permit early detection of a failure. Inspection is relatively easy for the external rapping and vibrating equipment common to U. S. designed precipitators.

8) Dust Removal System Breakdown

This AOC is produced by a myriad of causes. Among them are broken screw conveyor shafts, plugged dust valves, dust bridging or sticking in the hoppers, hopper heater failures, and hopper vibrator failures. Problems with dust removal are frequent and common to all plants using dry collection systems.

Failure of dust storage and removal equipment leads to full hoppers. When the dust level in the hoppers reaches the bottom of the discharge wires or the steadying frame that aligns them, two things can occur. The preferable occurrence is to have the TR set trip due to undervoltage (caused by shorting through the dust to ground). Collection will stop in the electrical section above the affected hopper and in any other section energized by the same TR set, thus preventing any damage to the internal components. If the undervoltage trip protection does not work or does not exist, the dust level will continue to rise and begin lifting discharge electrodes and their steadying frame. Permanent damage to the electrode system may be done in this case. Repairs to the steadying frame and wires require a precipitator shutdown more lengthy and costly than the usual repairs required by the dust removal system. Therefore, it is a better choice to shutdown the affected collecting area for repairs to the dust removal equipment.

Sometimes secondary problems develop from efforts to solve the primary problems. One of the methods chosen to break up dust plugs in the double flapper type dust valves is to strike the valve casings with a hammer. While the dust plug may be broken the valve casing is often bent thus preventing a good seal between the flapper valve and the valve seat. On negative pressure installations this allows dust to be drawn back into the precipitator along with cold air. The cold air may produce corrosion damage to the collecting plates and some of the dust bypasses the precipitator going uncollected. Because dust valves produce many sticking or plugging problems some operators remove them. This solution is only satisfactory if the hoppers are always left with enough dust at the bottom to act as a seal. If not, the same air inleakage problem will occur.

For the case where a section of the precipitator is deenergized, the increased particulate emissions can be calculated in the manner used for broken wires. Additional emissions resulting from air inleakage cannot be estimated.

The frequency of dust removal equipment problems is highly variable. An estimate of the range is one time per week to once per two months. Simple problems typically require at least an hour to correct. A more complex repair such as a conveyor shaft replacement might require eight hours to perform.

Impending problems with a dust removal system can be sensed with hopper dust level indicators. Level indicators can be placed at two levels in each hopper for a more complete picture of operations. Conveyor on/off indicators should be included in a good monitoring system. Regularly scheduled or continuous dust removal operations are important to prevent damage from overfilled hoppers.

Though operations may be attempted without them, hopper insulation, hopper heaters, and hopper vibrators contribute to more trouble-free operations according to plant operators. If nothing else, the insulation and heating prevent moisture condensation in the hoppers. Some people believe that hot dust is more fluid or less "sticky" than cold dust without considering the effects of moisture. The dusty environment of the dust valves and conveyor drives makes preventive maintenance and frequent inspections essential to minimizing AOC's.

Because of problems with screw conveyors at least one operator has designed a dust handling system to avoid the use of screw conveyors.[18] An enclosure was built under the precipitator hoppers. Dust falling from the hoppers passes through "star" dust valves into the enclosure. Dust is removed from the enclosure by a front end loader. Since the operation was not observed, it is not known if there are significant fugitive emissions from the loading operation or not.

Scrubbers Common

1) Sprays Corroded or Plugged

Sprays are used in several locations in a scrubber system applied to a BOP furnace. Sprays are used in the quencher or precooler upstream of the venturi

There are sprays in gas cooling towers downstream of the venturi. The sprays that most frequently cause performance problems are those in the venturi. Solids accumulation in particular is reported as a major cause. After the first year or two of use, presumably the best material of construction to avoid corrosion damage will have been chosen. However, excursions in the system pH occur in some plants causing unexpected corrosion problems. Acid scrubbing water conditions can exist if resulfurizing of steel is practiced or if the shop is equipped with auxiliary oil-fired waste heat boilers. The more typical situation, however, is an alkaline condition resulting from carryover of the lime used as a fluxing agent in the process. Because of the alkaline conditions, scaling is a significant factor for this AOC.

The result of improper atomization and/or insufficient water flow to the scrubber is reduced efficiency of particulate collection. In conventional variable throat venturi scrubbers with high pressure drop, scrubber efficiency may not decrease with decreasing liquid to gas ratio (L/G) over a range of L/G values. Some work done in West Germany has shown that scrubbing efficiency begins to decrease when the L/G drops below 0.6 L/scm (~ 5 G/1000 scf).[1] The exact quantitative relationship between decreasing water rate and scrubbing efficiency may be available from the scrubber manufacturer.

No direct data on frequency of plugging and/or corrosion of sprays were obtained. Related to findings on sprays for precipitators, a high estimate would be three times per week. A low estimate would be once per furnace campaign (about two months). Estimated time to repair the venturi sprays would be one to three hours after identifying the problem. The venturi sprays are more accessible then quencher or gas cooler sprays. Repair of these latter sprays may require more time.

Where spray damage is identified as a corrosion problem, special alloys must be considered for use. At least, stainless steel (Type 316 ELC) can be considered for resistance to sulfuric acid attack. In a recycle water system care must be taken with respect to chloride buildup. High chloride concentrations will attack Type 316 ELC stainless, so higher alloys such as Inconel 625 or Hastealloy C may be necessary for long life. The latter two are much more expensive than stainless steel. Alternatively, corrosion control may be attempted by pH control and corrosion inhibitors. If maintenance is provided at the end of each furnace campaign, the optimum choice may be partly material selection and partly chemical control. If the nozzle losses are caused by abrasion rather than corrosion, the higher alloys will not show much improvement in life over Type 316 ELC stainless.[26]

Where plugging is the problem, improvement of the water supply is important or alternatively a regularly scheduled down turn for scrubber maintenance can be used. Some scrubber designs have automatic reaming devices to clean the nozzles. These devices are effective primarily with good quality recycle water, 50-70 ppm suspended solids, but can be a maintenance problem with high solids content streams, e.g., 5 percent.[27]

The use of a scheduled down turn for maintenance is a successful approach. One plant utilizing this approach claims 90 percent of their total scrubber maintenance can be performed during these scheduled maintenance periods.[17]

Solids in the recycled water may be reduced by the use of polyelectrolytes to improve settling characteristics. If the plugging is due to scaling, use of scale inhibitors and pH control can be considered.

Maintenance of proper chemical balance in the recycled water system for a BOP furnace can be quite complicated due to the cyclic nature of the process. Wide variation in system pH from acidic to basic conditions and back can occur during each heat. Corrosion potential and scaling potential must, therefore, be examined together for the whole cycle and at numerous locations within the recycle water system where conditions change. One literature reference cites the experience of a British Steel Corporation plant that found their operation so complex they finally chose a once through scrubber water system.[28] Their conclusion was that each system must be studied and treated on an individual basis.

2) Plugged or Corroded Pipes

The cause of this AOC is scaling resulting from lime carryover from the BOP furnace or low pH due to acid removal from the gas stream. The discussion in the previous paragraphs on causes and solutions to the problems generally apply. Piping is considered less expendable than nozzles, however, and so more resistant (also more expensive) materials of construction may be chosen. In addition to higher grade alloy steel, rubber lining is used to avoid corrosion losses. One plant reported plugged or unbalanced water system problems (possibly caused by plugging) five times over a ten month period.[11] No duration was reported.

The consequences of plugged pipes may include reduced scrubber efficiency due to low water flow, and overflow of tanks or thickeners in the recycle water system leading to spills to the sewer. Corroded pipes can lead to spills to the sewer and inadequate scrubber water flow also.

3) Corroded Pump Impellers, Pump Failure

Discussion on corrosion problems and solutions in the previous two topics apply to corroded pump impellers. Pump failure can also be caused by abrasive wear to the impellers and motor failures. As in the case of the previous two AOC's low water flow may result in reduced scrubber efficiency. Most plants have installed spare pumps so that if one fails another can be brought into service.

In the event there is no spare available, the low flow condition could last two to eight hours before repairs are completed. One plant reported five pump failures over a ten month period in a BOP furnace scrubber system.[11]

Sensors to detect low water flow and the pump operating status are keys to early warning of an impending problem or a statement that a failure has occurred. Rubber lined pumps can be used to provide corrosion and abrasion protection. Alternatively, pH control and corrosion inhibitors can be used to avoid corrosion damage. If the system has no preclassifier to allow coarse, gritty material to settle before reaching the pumps, such a device may be installed to reduce abrasive wear. If a preclassifier does exist, its adequacy and its location in the system should be investigated.

4) Plugged or Failed Demister

All scrubbers have some sort of device to separate entrained water from the gas stream. The purpose is to prevent water droplets containing particulate matter from carrying out the stack and adding materially to the emission rate matter from carrying out the stack and adding materially to the emission rate or to prevent chemical damage due to the acid or alkalinity of the water.

The entrainment separator or demister is usually some type of baffled device that presents an impingement surface to the gas stream or a cyclonic separator. There is a potential for solids buildup to occur in these devices. The buildup results in reduced flow area and consequently increased pressure drop. Given a scrubber system with fixed fan capability, the static pressure developed must be used either upstream or downstream of the fan. If the mist eliminator pressure drop increases at the normal system flow rate, then the scrubber pressure drop must decrease by a corresponding amount. Alternatively the total gas flow rate may be decreased and the scrubber pressure drop maintained. In the later case fugitive emissions develop at the hood, in the former case the scrubber efficiency decreases.

The frequency and duration of this AOC are unknown. The increase in particulate emissions might be calculated if the scrubber pressure drop decreases. The scrubber manufacturer can supply a curve of outlet concentration versus pressure drop.

Pressure drop across the demister can be monitored and alarmed to give warning of a developing problem. Periodically the demister needs to be washed to prevent this AOC. A regularly scheduled weekly or monthly outage would allow an inspection to determine whether the washing is necessary. Plant experience should dictate the length of time between inspections.

5) Drum Filter Failure

Underflow from the thickener(s) in the recycle system is often dewatered by vacuum filtration either by rotary drum or disc-type. The vacuum system required in these installations are reported to be high maintenance items. A number of plants have found it necessary to retrofit spare filters as a result. One problem is apparently related to solids spillover into the vacuum pump resulting in abrasive wear.[6]

With no spare drum filter available and repairs that can be made within an hour or two, the AOC will not necessarily produce increased solids in the effluent. There is some solids surge capacity in a thickener. Longer repair means either solids spillover or all the underflow must be transported to the disposal site. The underflow gives a much larger volume to dispose of than the dewatered sludge. Depending on the disposal site liquid runoff could be a problem.

No data on frequency of occurrence were found, but the general impression from the operators was that it occurs frequently, with long enough repair times to justify a spare drum filter. Spare filter capacity then is a primary means of avoiding the AOC.

6) Acid Cleaning Scrubber Components

Acid washing of scrubber system components may be used periodically to remove accumulated scale deposits. Particularly the quencher, the venturi, the entrainment separator, the gas cooling tower, pumps, pipes, and nozzles are susceptible to scale deposits that impair scrubber system operation. The acid wash itself is not an AOC if precautions are taken to prevent spilling to the sewer without neutralizing.

Review of NPDES data shows that spills do occur. Data from one plant showed low pH discharges (< 6.0) for periods of 10 minutes to 3 hours due to acid washing of various plant scrubbing systems, including BOP furnaces and blast furnaces.[29] Over a period of 18 months, this AOC occurred twice for the BOP furnace system and four times for the blast furnaces. Prevention of this AOC is possible by proper planning. Piping, pumps, and tanks can be arranged to capture the used acid, settle suspended solids, and neutralize the acid before discharge.

7) Unbalanced Water System

In a recycle water system typical of BOP furnace scrubbing systems, surge capacity exists at several locations. Thickeners, recycle tanks, and classifiers have some capacity to store surges. With multiple pump groups in the system, it is possible to have a water imbalance within the system. Too much water may flow to the thickeners while a lower amount is pumped away. The net result is an increasing water level in the thickener. Taken to the extreme, this situation leads to overflows or spills to the sewer. Depending on the spill source, pH and/or suspended solids may exceed the effluent guideline limitations.

A pump failure without a spare, or plugged pipes can also lead to this AOC. Another cause is poor coordination of system operations. Successful operation of a recycle system may require the attention of a full-time operator. Proper monitoring of system status must include level sensors in the tanks or other holding equipment, pumping rates, and on/off status of the pumps.

One plant reported unbalanced or plugged water systems to have occurred five times in a ten month reporting period.[11] No duration was reported for these incidents nor was there any indication whether spills resulted.

Baghouse Common

1) Bag Breakage or Plugging

Baghouse applications in the BOP shops in the United States are all for secondary particulate emissions control. The first baghouse application to control of primary vessel emissions is at present in the design stage.[20]

Applications to hot metal transfer, charging and tapping, slag raking, and desulfurization run the risk of having bag failures from spark carryover. In some instances sparks are conveyed through the duct system into the bags, burning holes in the bags. Usually there are some devices installed in the gas flow stream to prevent this, but it still can happen.

The other failure, plugging or blinding of the bags, can result from moisture condensation, oil vapor, or fine particulate in the gas stream. Fine particulate can be collected readily by fabric filters given the proper choice of fabrics and appropriate operating procedures. When using new bags on a fine particulate, the manufacturer may recommend precoating the bags with a coarse particulate to prevent blinding. Preconditioning of the fabric may even be recommended periodically after cleaning cycles. The plugging AOC refers to blinding caused by poor choice of fabric or operating practice not consistent with achieving long bag life.

With spark damage, particulate will pass through the burned bag uncollected. If bag plugging occurs, draft on the process hood(s) will be decreased, increasing fugitive emissions from the hood periphery. The rate of increased emissions when bag breakage occurs depends on the number of bags affected. The increase in fugitive emissions from plugging depends on how much draft reduction occurs. In neither case is the increased emissions readily calculable. While completely shut down, the emissions are as reported in the Section on Downtime of Secondary System.

When spark carryover occurs it often only affects a few bags. If the baghouse is well designed, one compartment at a time can be isolated and bag replacement made while the rest of the unit is in operation. This procedure minimizes increased emissions by avoiding a complete shutdown of the baghouse. Bag blinding or plugging, on the other hand, tends to affect most of the bags instead of a few. It is more likely to necessitate a complete shut down for bag replacement. Obviously, in a shop that takes a weekly down turn for maintenance, the probability of long emission producing outages will be minimized.

Erie County, New York supplied data for one plant showing three outages in a year for bag inspection and replacement on a hot metal transfer baghouse. The duration of these was 13, 17, and 96 hours.[30] Another plant reported frequent bag replacements for a hot metal transfer baghouse without indicating whether complete shutdowns were necessary.[17] The latter plant does have a weekly maintenance down turn; presumably some replacements were accommodated in this way. A third plant reports this AOC frequency to be four to six times per year.[14]

Baghouse design with an extra compartment (above that required for normal cycle with one down for cleaning) and compartment isolating capability is a useful means of minimizing increased emissions during this AOC. A weekly shop-wide maintenance turn is also an effective method.

2) Shaker or Reverse Air System Failure

Shakers or reverse air cleaning are common ways to perform bag cleaning. Either of these systems may break down in such a way as to affect a single compartment or the entire baghouse. When not operating, dust continues to buildup on the bags in the affected compartment(s) thus increasing the pressure drop and reducing gas flow.

If a single compartment is the scene of the problem, the other compartments must gradually absorb the gas and dust load from that compartment as the situation worsens. The ultimate effect is increased pressure drop through the entire baghouse or reduced flow that leads to increased fugitive emissions.

Data from a hot metal transfer baghouse reported by Erie County, New York showed four failures in one year due to problems with shaker cleaning equipment.[30] The duration for repairs varied between 2 and 17 hours. While shut down, the increased particulate emissions for hot metal transfer are about 0.25 to 0.35 kg per metric ton (0.5 to 0.7 pounds per ton) of steel produced.[23]

Efforts to minimize emissions for this AOC should be directed toward frequent inspection of the cleaning mechanism and preventive maintenance.

3) Open Bypass Damper

The extent to which this is a problem for secondary emissions systems is not known. It does occur in many fabric filter installations exhausting hot process gases. The operations typically controlled by baghouses in the BOP shops involve molten metal, but large quantities of ambient air are also aspirated giving a mixture much lower in temperature than the process. It is common for baghouses connected to hot processes to have bypasses or dilution air dampers. Dilution air dampers admit more ambient air to the duct to cool the gas, but consequently reduce the draft on the process hood(s). A bypass damper would allow the emissions to escape directly to the atmosphere. Of the two, the dilution air damper is a better choice from an emissions standpoint in that there is a lower increase in emissions as compared to bypassing the baghouse.

No data on frequency and duration of this AOC are reported. A complete bypass of hot metal emissions, for instance, would produce the same level of emissions cited for complete shut down of the system. Bypassing for charging and tapping would similarly produce the emissions cited for complete shut down of the system.

4) Dust Removal System Breakdown

This AOC is produced by a myriad of causes. Among them are broken screw conveyor shafts, plugged dust valves, dust bridging or sticking in the bypass, hopper heater failures, and hopper vibrator failures. Problems with dust removal are frequent and common to all plants using dry collection systems.

Failure of dust storage and removal equipment leads to full hoppers. When the dust level reaches the bottom of the bags it begins to reduce the available filter cloth area. Pressure drop has to increase if the same flow is maintained or pressure drop can remain the same if flow rate is reduced. The former may produce a higher residual dust cake (after the bags are cleaned) and the latter reduces draft at the process hood.

Sometimes secondary problems develop from efforts to solve the primary problems. One of the methods chosen to break dust plugs in the double flapper type dust valves is to strike the valve casings with a hammer. While the dust plug may be broken, the valve casing is often bent thus preventing a good seal between the flapper valve and the valve seat. On negative pressure installations this allows dust to be drawn back into the baghouse along with cold air. The cold air may produce corrosion damage to the metal internals and some of the dust will return to the bag surface. Because dust valves produce many sticking and plugging problems some operators remove them. This solution is only satisfactory if the hoppers are always left with enough dust at the bottom to act as a seal. If not, the same air inleakage problem will occur.

Deactivation of a compartment due to dust buildup will increase the burden to the other compartments resulting in a higher pressure drop and reduced gas flow. This leads to increased fugitive emissions. The increase cannot be readily calculated.

The frequency of dust removal equipment problems is highly variable. An estimate of the range is one time per week to once per two months. Simple problems typically require at least an hour to correct. A more complex repair such as a conveyor shaft replacement might require eight hours to perform.

Impending problems with a dust removal system can be sensed with hopper dust level indicators. Level indicators can be placed at two levels in each hopper for a more complete picture of operations. Conveyor on/off indicators should be included in a good monitoring system. Regularly scheduled or continuous dust removal operations are important to prevent damage from overfilled hoppers.

Though operations can be maintained without them, hopper insulation, hopper heaters, and hopper vibrators contribute to more trouble-free operations according to plant operators. If nothing else, the insulation and heating prevent moisture condensation in the hoppers. Some people believe that hot dust is more fluid or less "sticky" than cold dust without considering the effects of moisture. The dusty environment of the dust valves and conveyor drives makes preventive maintenance and frequent inspections essential to minimizing AOC's.

Because of problems with screw conveyors at least one operator has designed a dust handling system to avoid the use of screw conveyors.[18] An enclosure was built under precipitator hoppers. Dust falling from the hoppers passes through "star" dust valves into the enclosure. Dust is removed from the enclosure by a front end loader. Since the operation was not observed, it is not known if there are significant fugitive emissions from the loading operation or not.

Fan Common

1) Draft Loss

Draft losses in a system other than complete fan failures are produced by corroded or eroded fan blades, leaks in the system ductwork, and leaks in the process hoods. All of these problems develop over a period of time. Causes of corrosion and erosion are those things cited in the discussion of spray nozzles, pipes, etc. Leaks in ductwork and hoods develop from the continual expansion and contraction of metal in the system, characteristic of BOP cyclic operations.

Draft losses reduce the gas flow withdrawal from the process hood. Increased fugitive particulate emissions result. These fugitive emissions would be visible as increased roof monitor emissions. A conceivable means of estimating the quantity of increased emissions would be to observe and estimate the hood capture efficiency as compared to normal operations. The percentage of uncaptured emissions can be multiplied by the uncontrolled emission rate to yield an answer. Admittedly the estimate is partially subjective, but a rough estimate may be obtained in this manner.

For primary BOP control systems it may be necessary to do some hood panel closing or welding after each vessel campaign, perhaps once per month to two months. One plant reported cleaning or replacing portions of a hot metal transfer hood about once per year.[17] A lead fume control hood was cleaned or portions replaced five times in one year.[17] Duration of poor draft conditions in these cases was not supplied.

Since most of these problems develop gradually, preventive maintenance is a good method to minimize emissions from this AOC. Reduction of corrosion and erosion losses may be achieved through careful selection of construction materials and the use of lined or protectively coated surfaces.

2) Fan Failure

Common causes of fan failures include high bearing temperature, vibration, loss of bearing oil, and motor failures. Vibration can be produced when particulate deposits on the fan blades in an uneven manner and when corrosion or abrasion destroys metal on some blades leaving the fan wheel out of balance. It is common practice to highly instrument fans, especially those of the primary control systems. Bearing temperature, cooling water flow, and vibration monitors are used to sense impending problems with fans.

Fan failures in a single fan system shut down the entire control system leaving all the process emissions uncontrolled. In multiple fan systems, especially for primary control, a single fan failure probably will not have any environmental effect other than that of starting a spare fan.

If two fail simultaneously, blowing rate may have to be reduced to have sufficient drafting capacity. If the blowing rate is not reduced increased particulate emissions will result.

Fan failures from the above causes were reported to occur four to ten times per year. The durations were estimated to be in the range of 8 to 48 hours.[11,31] One plant indicated they matched their blowing rate to the available fan capacity.[11] Another indicated they would complete the heat in progress, then shut down until repairs are complete.[31] Fan fialure in a suppressed combustion system would mean no further operations until repaired or the heat would have to be completed with an open hood at low enough blowing rates to prevent damage to hood panels.

The increased particulate from a partially complete heat would be some fraction of the 6 to 20 kg per metric ton (12 to 40 pounds per ton) of steel reported earlier as uncontrolled emissions.[1,2,3] Early sensing, preventive maintenance, and spare fan capacity all are means of minimizing this AOC.

Other

1) Loss of Instrument Air

Control instrumentation in some plants is pneumatically operated. If the air supply to the instruments fails, flow control devices and other equipment (fans) go to the fail-safe mode to prevent damage, explosions, etc. One plant with a suppressed combustion control system uses pneumatic instrumentation. Fan losses were reported to have occurred six times over a ten month period for two vessels due to instrument air loss. The duration of the AOC was not reported. In this system, the oxygen lance retracts under this condition. The sudden fan loss may cause no environmental effect other than a puff, if the fans can be started quickly enough to complete the heat. Otherwise, it would be necessary to complete the blow uncontrolled and dump the heat.

2) Failure to Flare Gas

This also is an AOC that affects suppressed combustion systems. All of the systems must flare off unwanted carbon monoxide. Failure to flare results from igniter failure. One plant reported this to occur three times over a ten month period in a two vessel shop.[17] Carbon monoxide will continue to be vented during each blow until the igniter or pilot is restored to service. The flare may be tied to oxygen lance retraction, in which case the blow will be interrupted upon failure.

For a 227 metric ton vessel (250 tons) the approximate amount of CO released unflared is 25,000 scm (900,000 scf) per heat assuming 10 percent combustion of CO_2.

5.0 TABULATED SUMMARY OF AOC

Table 2 summarizes the AOC's described herein. The identification of an AOC carries no implication whatsoever concerning liability for resulting air or water pollution. Liability for an AOC can only be determined by the enforcement officer responsible for a given set of regulations (NSPS, SIP) or permit requirements (NPDES, special conditions, etc.).

TABLE 2. BASIC OXYGEN PROCESS ABNORMAL OPERATING CONDITIONS

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
PROCESS RELATED -- STARTUP							
Burn In	Burning tar bonded linings	None	None available	1/2 to 2/month	Up to 2 hours	Emissions of carbonaceous fumes	7,11
PROCESS RELATED -- SHUT DOWN							
Vessel lining dump	Dumping broken refractory material by rotating vessel	None	None available	1/2 to 2/month	1 min	Particulate from dust cloud	
PROCESS RELATED -- ABNORMAL OPERATING CONDITIONS							
Puffing at hood	Poor hood draft, rapid furnace reactions	None	Repair gas leaks, improve process control	Variable	1-20 mins	Waste gas emissions overflow hood to roof monitor	12
Improper ladle to vessel hot metal transfer	Pouring too fast, improper furnace angle	None	Slow pouring, proper furnace angle	Variable	1-3 mins	Excess charging emissions	17, Est.
Relief damper opening	High gas temp., or combustible content of gas	May cause lance to retract	Stop oxygen blow. Improved process control	1 to 10/month	20 sec to 20 min	Waste gas directly to atmosphere, 6-20 kg/metric ton of steel if total blow	1,2,3,11, 12
Foaming and slopping	Excess oxidation of slag, eroded lance nozzle	Decreased product yield	Revised furnace practice, lance mtn. initial design of vessel	2/week, could be up to 25% of heats	1-5 mins	Particulate emissions from spilled material	11,12,14
Pit or charging explosions	Water in pit or scrap	Possible equipment damage, metal loss	Avoid water leaks or spills	3/yr - pit 1/yr - charge	20 sec	Stirs up settled dust, may damage equip. or injure personnel	Est.,17
Improper charge material	High silicon, hot metal, dirty scrap	Excessive charging reactions	Improved control of scrap quality, quality control of hot metal	2/week	1-3 mins	Increased fugitive emissions from charging operation	Est.

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
Running stopper	High FeO slag, poorly set nozzle or rod, cold heat with a skull	Loss of yield	Improved practice of setting rods and nozzles. Consider use of slide gates	3/month	30-60 mins	Stirs up pit dust, roof monitor iron oxide emissions	17,31
			CONTROL EQUIPMENT RELATED -- STARTUP				
Stack puff	Startup out of service fan	None	None available	1/week - 1/yr	1-60 mins	Particulate emissions from dust on duct floor or louvers	6,11
Insufficient draft	Failure of spare fan to start due to ice in housing	Reduced draft	Run fan at idle after mtn., reduce blow rate to match capacity	0-3/yr	Several hours unless blowing rate is reduced	Particulate emissions spillover hood	6,Est.
Unbalanced flow among manifolded fans	Restarting a down fan in a multiple fan system	None	Attention to design of system ductwork and manifolds	1/week - 1/yr	12-16 hours	Increased particulate emissions due to overload on some collector chambers	6
Precipitator warmup	Manufacturer's recommendation	None	Reduced voltage operation, increased rapping intensity	1/week - 1/month for chambers. 1/yr - 1/5 yrs for whole precipitator	10-20 mins	Increased particulate emissions to air, could be 6-20 kg/metric ton of steel if not turned on during blow. It usually turned on part way through the blow.	18,Est.

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
CONTROL EQUIPMENT RELATED -- SHUT DOWN							
Dampers stuck open or jammed and leaking	Dirt on sealing surfaces or inoperative electrical controls	Reduced draft on operating vessel hood	Repair controls, clean surfaces, preventive mtn., improved damper design	1/month - 2/yr	1-24 hours	Increased emissions due to hood spillover caused by re-reduced draft	11,19
CONTROL EQUIPMENT RELATED -- ABNORMAL OPERATING CONDITIONS							
Downtime of primary collection systems	Power failure	May or may not shut down process	Preventive mtn.	3/yr - 1/5 yrs		All emissions direct to atmosphere unless blow is stopped (6-20 kq/metric ton)	1,2,3,6,7,17
	Pump failure	May or may not shut down process	Provide spare capacity				
	Fan failure	Reduced blowing rate	Provide spare capacity Oxygen lance retraction can be added to all of the above				
	Clarifier rake failure		Provide spare capacity	0-2/74	1-3 days	Increased solids in blowdown, increased blowdown	
Downtime of Secondary Systems							
Charging and tapping	Same as primary	None	Preventive mtn., installed spare capacity	30/yr	Charging - 2 mins/heat. 1/2hr - 13 days Tapping - 4 mins/heat	Particulate - 0.13 kg/metric ton of steel Particulate-0.1 kq/metric ton steel	11,22,23

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
Hot metal transfer	Fan failure, power failure, open bypass damper due to high temp. or pressure drop, screw conveyor failure, cleaning	None	Preventive mtn., installed spare capacity	18-47/yr	2-4 mins/pour or 1-96 hours overall	Particulate - 0.25 0.35 kg/metric ton of steel released to air	11,21.22,23
Flux handling	Power failure, fan failure	None	Preventive mtn., installed spare capacity	1-8/yr	2-3 hrs/day	Particulate - 0.75 kg/metric ton released to air	Est.
Slag raking and desulfurization	Power failure, fan failure, open bypass damper	None	Preventive mtn., installed spare capacity	Not available	5-20 mins/heat	Particulate released to air	Est.
Precipitator - Common							
Wire breakage	Corrosion, high spark rate	None	Replace with shrouded wires or higher strength wires	2-12/yr	8 hrs-14 days	Increased particulate emissions, can be calculated, see text	6,7,18,24, Est.
Sprays plugged or corroded	Solids in water, pH problems	None	pH control, improved materials, frequent inspection and mtn.	3/week - 1/month	Continuous until repaired, 1-3 days	Increased particulate emissions due to high resistivity	14,18,24
Insufficient conditioning of gases	Low temp. gas, lag time	None	Use steam injection during charging and start of blow	1/heat	1-6 mins	Increased emissions due to high resistivity	24,32
Corroded pump impellar, pump failure in spray system	Improper pH control, motor failure	None	pH control, preventive mtn.	Variable	2-8 hours	Increased emissions due to high resistivity	Est.
TR set failure	Age, overheating	None	Air condition control enclosure	1/yr to 1/2 yrs	2 hours - 1 month	Increased particulate emissions, can be calculated, see text	Est.

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
Cracked insulator	Dust on insulator	None	Replace, clean and inspect frequently	2-4/yr	1-12 hours	Increased particulate emissions, can be calculated, see text	21,25
Rapper or hopper heater burned ou	Age, low reliabilit	None	Replace, inspect and maintain frequently	Not available	Not available	May cause increased emissions	
Dust removal system breakdown	Screw shaft broken, dust valve plugged, dust bridge in hopper	None	Use of hopper heaters, heat insulation and hopper vibrators, level indicators	1/week - 1/2 months	1-8 hours	Increased emissions when section shut down, can be calculated, see text	11,21
Scrubber-Common							
Sprays corroded or plugged	Low pH, solids in water	None	pH control, improved settling by chemical additions, control of scaling conditions	3/week - 1/2 months	1-7 hours	Reduced scrubber efficiency	Est.,9,11,14, 18,24
Plugged or corroded pipes	Low pH, scaling	None	pH control, corrosion inhibitors, scale inhibitors	6/yr	3 hours	Reduced scrubber efficiency	11
Corroded pump impellars, pump failure	Low pH, motor failure	None	pH control, corrosion inhibitors, scale inhibitors, Preventive mtn.	6/yr	2-8 hours	Reduced scrubber efficiency	Est.,11
Plugged or failed demister	Scaling, solids carryover	Increased pressure drop, may shut down process	Wash demister (may be acid wash) Use centrifugal demister	Not available	Not available	Increased hood spillover as draft decreases	
Drum filter failure	Vacuum pump failure due to solids spillover	May cause shut down if no alternate sludge handling available	Spare capacity	Not available	Not available	Suspended solids in blowdown may increase, watery sludge, may have to be landfilled	6,7,19

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
Acid cleaning scrubbers overflow to sewer	Insufficient planning for handling wastes	None	Capture and neutralize acid	1/yr	10 mins - 3 hours	pH < 6.0 for discharge	29
Unbalanced water flow	Poorly coordinated system operation	None	More surge capacity, better operator training, and communication	6/yr	Not available	Spill of untreated wastewater	6,17,19
Baghouse-Common							
Bag breakage or plugging	Spark carryover, overloaded bags, moisture or oil carryover	May be reduced draft	Spare compartments	3-6/yr	13-96 hours	Increased particulate for bag breaks, reduced draft and increased hood emissions for plugging	14,21
Shaker or reverse air system failure	Low reliability, lack of mtn.	None	Preventive mtn., frequent inspection	4-6/yr	2-17 hours (1 compartment-1 wk)	Increased particulate emissions	17,21
Open bypass damper	High temp. due to cooling failure or high pressure drop	None	Frequent inspection Preventive mtn.	Not available	Not available	All process particulate to atmosphere	
Dust removal system breakdown		(SEE	PRECIPITATOR-COMMON)				
Fan-Common							
Draft loss	Corroded or eroded blades, leaks in duct and hoods	May need to reduce blow rate	Preventive mtn., coat exposed surfaces, resistant materials of construction	1/month - 1/year	1-17 days	Increased hood emissions	17,18
Fan failure	High bearing temp., vibration, loss of bearing oil	Reduced draft	Interrupt blow, preventive mtn during scheduled downturn	4-10/yr	8-120 hours	Total or partial discharge of pollutants to atmosphere	11,31

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Observed Frequency	Duration	Environmental Effects	Reference
Other							
Loss of instrument air	Various	Will shut down process, but blow might be completed if repair requires lengthy shut down		6/yr per 2 vessels	1 hour	Discharge blowing emission to atmsphere if lance is not retracted	17,
Failure to flare gas	Igniter failure	May cause oxygen lance retraction	Repair igniter	3/yr in 2 vessel shop	Length of blow	CO emissions about 25,000 scm per blow for 227 metric ton vessel at 10% combustion	17, Est.

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